Pavement Markings

TRAFFIC

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **130**

ROADWAY DELINEATION SYSTEMS

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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ROADWAY DELINEATION SYSTEMS

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AREAS OF INTEREST:
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- GENERAL MATERIALS
- MAINTENANCE, GENERAL
- HIGHWAY SAFETY
- TRAFFIC CONTROL AND OPERATIONS

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The study reported herein was undertaken under the aegis of the National Academy of Sciences—National Research Council. The National Cooperative Highway Research Program, under which this study was made, is conducted by the Highway Research Board with the express approval of the Governing Board of the NRC. Such approval indicated that the Board considered that the problems studied in this program are of national significance; that solution of the problems requires scientific or technical competence, and that the resources of NRC are particularly suitable to the conduct of these studies. The institutional responsibilities of the NRC are discharged in the following manner: each specific problem, before it is accepted for study in the Program, is approved as appropriate for the NRC by the Program advisory committee and the Chairman of the Division of Engineering of the National Research Council.

The specific work to be performed in each problem area is defined by an advisory panel that then selects a research agency to do the work, monitors the work, and reviews the final reports. Members of the advisory panels are appointed by the Chairman of the Division of Engineering of the National Research Council. They are selected for their individual scholarly competence and judgment, with due consideration for the balance and breadth of disciplines.

Responsibility for the definition of this research project and for the publication of this report rests with the advisory panel. However, the opinions and conclusion expressed or implied are those of the research agency that performed the research, and are not necessarily those of the Highway Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway Officials, nor the individual states participating in the Program.

Although reports in this category are not submitted for approval to the Academy membership nor to the Council, each report is reviewed and processed according to procedures established and monitored by the Academy's Report Review Committee. Such reviews are intended to determine, *inter alia,* whether the major questions and relevant points of view have been addressed, and whether the reported findings, conclusions and recommendations arose from the available data and information. Distribution of the report is permitted only after satisfactory completion of this review process.

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FOREWORD

By Staff

Highway Research Board

This report will be of particular interest to traffic and highway engineers who are responsible for the design and specification of roadway delineation treatments and systems. It is a valuable catalogue of information on treatment applications and materials, and provides a thorough review of psychological and economic factors as they influence delineation effectiveness. Guidelines are provided to assist the decision-maker in the selection and evaluation of alternative roadway delineation systems. Several laboratory and field experiments were conducted to provide background information for the effective use of the evaluation guidelines and to formulate recommendations for specific treatments in several "classical" highway situations.

Pavement and roadway delineation treatments do aid drivers in controlling their vehicles, thereby improving the safety aspects of the highway and easing the driving task—especially during adverse weather conditions and at night. The significant unanswered questions have been: How, how much, and with what cost-effectiveness? The research reported herein was carried out by the Pennsylvania State University to seek answers to these questions. Seven tasks were set forth to serve as the research framework: (1) review past and current research; (2) prepare a state-of-the-art summary; (3) determine the driver's delineation requirements; (4) establish rational techniques for determining the effectiveness of delineation treatments; (5) test promising delineation systems; (6) develop practical criteria for the selection of delineation treatments; and (7) evaluate colored pavements.

A comprehensive state-of-the-art summary is provided as the result of an extensive review of current practices and the literature. Reported applications of delineation treatments at various geometrical situations are synthesized and evaluated; materials used, with their cost and maintenance problems, are discussed; relevant visibility, information processing, and cost-effectiveness studies are reviewed; and a summary of practices in other countries is provided to further illustrate the wide variety of delineation systems in current use.

Information requirements for the "classical" geometric situations are presented in flow charts developed from a task analysis of the required maneuvers. The task analysis consisted of defining the desirable driver actions, then working backward to the required information on which driver decisions could be based. The first of a three-part Guideline Form is provided to integrate the results of the task analysis with accident experience to more specifically define information requirements at a given location.

The second part of the Guideline Form provides a structure for rationally evaluating the effectiveness of alternative delineation treatments. A combination of objective and subjective judgment is required. The laboratory and field studies provide some objective data for these evaluations, and considerable background concepts and experimental data for the subjective judgments.

Results of several studies involving installation of alternative treatments at specific sites are included in the appendices. These studies include variations in color and patterns of post delineators at horizontal curves, the use of raised pavement markers with and without edge lines at horizontal curves, variations in color and spacing of post delineators at stop approaches, and the preliminary evaluation of a less-costly center line pattern on rural two-land roadways.

The complete Guideline Form provides a structure for a well-reasoned selection of delineation treatments. The remainder of the material in the report was developed to assist the decision-maker in effective use of this Guideline Form. Further, recommendations are included for the application of the various delineation treatments and systems in each of the "classical" geometric situations.

The research indicates that wear- and skid-resistance properties of colored pavements are superior to those of standard asphaltic overlays. Widespread application is not foreseen, however, due to the relatively high cost of these treatments and problems associated with nighttime visibility.

The report also contains suggestions for several potentially fruitful research areas that have become evident as a result of this study. It indicates that more research is needed in correlating various intermediate measures of effectiveness with actual accident experience. Inasmuch as subjective judgments will remain a primary basis for selection and specification of delineation treatments and systems, attention should be directed toward optimizing the effectiveness of these procedures.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 5-7 by The Pennsylvania State University, Transportation and Traffic Safety Center, with James I. Taylor, Associate Professor of Civil Engineering, as Principal Investigator and Hugh W. McGee as chief Research Assistant. The project was under the general administration of Thomas D. Larson, Director of the Pennsylvania Transportation and Traffic Safety Center. Grateful appreciation is also extended to those members of the PTTSC staff who assisted with drafting, editing, and typing of the report, and technical aid in the preparation of the material included.

Major subcontractors were the Institute for Research, State College, Pa., and Wayne State University, Detroit, Mich. The primary efforts at the Institute for Research were directed toward the human factors aspects of the study, including driver information requirements, under the direction of Edmond L. Seguin, Senior Research Associate. Wayne State University provided assistance in the colored pavement studies and the accident analyses, under the direction of William C. Taylor, Associate Professor of Civil Engineering.

Other staff members at these three institutions who contributed to the project in various ways included the following:

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Persons primarily responsible for the preparation of the various appendices are noted on the respective title pages.

Other agencies that contributed to this study are listed in Appendix W. Grateful acknowledgment is made to these agencies and their personnel who contributed time, advice, and expertise.

ROADWAY DELINEATION SYSTEMS

SUMMARY

Roadway delineation treatments and systems are specified and installed to aid drivers in controlling their vehicles, thereby improving the safety aspects of the highway and easing the driving task. There is a logical process by which installation decisions have been and are being made. The information developed in this research project provides meaningful and usable means to strengthen the decision process and enhance the likelihood of cost-effective solutions.

A comprehensive state-of-the-art summary covering the application of various delineation treatments to highway situations, delineation material properties, the human factors literature pertinent to delineation, and cost effectiveness considerations was compiled. Emphasis was given to current practices—particularly departures from the standard manuals—and recent research findings. Practices and research results of other countries were included.

Specific driver performance requirements at eight "classical" geometrical situations were defined. An Information-Decision-Action (IDA) task analysis procedure was utilized to translate performance requirements to information requirements. Essentially, the desired actions were defined, the decisions necessary to effect these actions were determined, and the information needed by the driver to make the required decisions was then specified.

The experimental program consisted of two major types of studies. Laboratory studies, conducted primarily by experimental psychologists, were carried out to develop and evaluate concepts basic to all delineation requirements, such as positive vs negative delineation, clutter of the visual environment, overdelineation, target value, and the various aspects of color and shape coding. Field experiments, directed primarily by the engineers on the project staff, were conducted under naturalistic conditions to evaluate the effectiveness of specific treatments or systems at specific situations. Studies included the use of post delineators and/or raised pavement markers at horizontal curves, the use of colored pavements, variations in center line marking patterns, and variations in color and spacing of post delineators at stop approaches.

Recommendations for the application of the various treatments at each of the "classical" situations were drawn up on the basis of these studies, discussions with other researchers and practicing engineers, and careful review of the literature. Widespread and consistent application of these recommendations will lead to reductions in accident experience and significant intangible benefits, such as increased driver comfort and reduction of uncertainty in critical situations.

In delineation, the major safety benefits come from the presence of the standard treatments as opposed to their absence; these benefits can be verified through accident records. Intermediate measures (such as means and variances of speeds, lateral placements, points of lane change) can be conveniently used to evaluate major changes in treatments; but these measures are characterized by certain limitations that require that they be supplemented by subjective evaluations. Inasmuch as these same intermediate measures are generally insensitive to minor variants in delineation treatments, it is necessary to rely more heavily on subjective methods (such as

teams of experts, diagnostic teams, and driver preference surveys) to evaluate changes in patterns, spacings, positioning relative to the roadway, etc.

Guideline Forms are provided to formalize and structure the decision-making process, ensuring consideration of the important factors in their proper relationship. These forms are flexible enough to accommodate the wide ranges in objective and subjective data inputs expected in decisions on delineation practices.

Delineation Task Forces are called for in each state to assure continuous study of delineation problems. These task forces could design and review extensive test installations, carry out long-term evaluations based on accident reductions, and make short-term decisions based on more subjective evaluations.

"Hard" research on variants in delineation treatments is not likely to be fruitful. Validation of the correlations among intermediate measures and accident experience was initiated in this project. Further work along these lines is recommended, as establishment of such relationships will permit benefit/cost analyses to be made more objectively. On the other hand, because subjective evaluation techniques will continue to play a major role in delineation decision making for the foreseeable future, these techniques should be developed more fully.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROJECT OBJECTIVES AND SCOPE

Vehicles running off the road constitute a substantial portion of the accidents on the highways of the United States. Improved pavement and roadway delineation systems may aid drivers in guiding their vehicles, thus improving the safety aspects of the highway and easing the driving task, especially during adverse weather conditions and at night.

Delineation techniques have also been used to provide guidance and regulatory information relative to special purposes such as left turns, right turns, speed changes, crosswalks, reversible lanes, channelization, no-passing zones, and pavement width transitions. These needs must also be recognized in the development of a complete delineation system.

Present delineation treatments include the use of pavement markings, post delineators, raised pavement markers, colored pavements, rumble strips, curbs, and indirect methods (intentional and non-intentional) such as contrasting shoulders, reflectorized guardrails, rows of luminaires, parallel fence lines, and advertising signs. However, only limited information is available concerning the effectiveness of the various devices.

Accordingly, this research effort was initiated in September 1968. The specific objectives of the study were:

1. Review past and current research pertaining to roadway delineation.
2. Prepare a state-of-the-art summary of the review.
3. Determine the driver's delineation requirements during various conditions, such as traffic, weather, highway geometry, and illumination.
4. Establish rational techniques for determining the effectiveness and the detrimental side effects of delineation treatments. Using the techniques established, evaluate existing and proposed delineation systems.
5. Test the more promising delineation systems. This testing should employ, but should not necessarily be limited to, one or more of the following:
   (a) Laboratory-type simulators.
   (b) Off-highway test tracks.
   (c) Operating highways.
6. Develop practical criteria for the selection of delineation treatments, including factors of cost effectiveness and maintenance problems.
7. A portion of the effort devoted to the evaluation of colored pavement for guidance purposes should include evaluation of the physical characteristics of colored pavements and comparison of their performance with that of conventional asphaltic and portland cement concrete pavements.

The scope of the research effort was further constrained by the following considerations:

1. The study concentrated on delineation of rural two-lane roads. It was believed that the maximum benefit of improved roadway delineation would occur on rural highways rather than in urban areas or on high-type freeways.

2. Exit and entrance ramps did not receive major consideration in this project. It is believed that so many parameters affect the accident rate at exit and entrance ramps that it would be very costly to determine the effects unique to delineation. However, considerable attention has been directed toward the delineation of freeway ramps by others, and the results of these studies are reflected in the state-of-the-art summary.

The terms "delineation technique" and "delineation system" are used to convey various meanings in the general literature. Hence, operational definitions were formulated and adopted as working guidelines for this project, as follows:

- A *delineation technique* is one of several types of devices and/or treatments (reflective striping, post delineators, etc.), excluding signs not specifically related to a delineation system, that provide guidance, regulatory, or warning information to a driver.
- A *delineation system* is a collection of techniques and/or treatments that together form an organized pattern or network of information that serves to distribute and/or manipulate vehicular traffic over a specified section of roadway for a specific purpose(s).

For example, a delineation system for a lane-drop situation might consist of an early cue sign, zebra striping, lane-drop signs, color-coded reflective delineators for the transition section, and possibly colored pavement (collection of techniques and treatments). The sequencing and placement of these components (an organized pattern or network) would indicate to drivers approaching a lane-drop situation (a specified section of roadway) how and where they should effect their lane-change maneuver (specific purpose) in order to minimize disruptions in the traffic flow (distribution and manipulation of vehicular traffic).

RESEARCH APPROACH

The decision-making process used to arrive at the solution to any delineation problem is shown schematically in Figure 1, and is outlined here to indicate the relationships among the various tasks and studies completed in this project. The research efforts were directed toward strengthening the basic inputs and using the procedure outlined in Figure 1 to arrive at recommended treatments for specific problems/situations. In the process, guidelines for optimizing utilization of the procedure to evaluate various alternatives and arrive at "best" delineation practices were developed.

The remainder of this section shows the interrelationships among (1) the objectives as stated in the original problem statement, (2) the items shown in Figure 1, (3) the individual research tasks completed, and (4) the report structure.

Problem Analysis. The first working item, the Problem Analysis, is in direct response to objective 3 of the original problem statement.

A Problem Analysis Guideline Form was developed as a tool by which the traffic engineer can systematically tie together accidents, driver/vehicle movements, and information requirements and deficiencies—all within the context of specific roadway situations. The Guideline Form is a result of a rational analysis of current practices, observations and consultations, the state-of-the-art summary, and the situation models reported in Appendix A.

The Guideline Forms for the "classical delineation situations," and a description of their development, are included in Appendix R.

State-of-the-Art Summary. An extensive literature survey was completed, using the forms shown in Appendix U, and covering the items listed in the bibliography (Appendix V). This effort was undertaken in fulfilling objectives 1 and 2 of the original problem statement.

Research reports and general information on current delineation practices were obtained from the highway departments through use of a form letter. Visits were then made to eleven state highway departments to conduct interviews and view actual delineation practices in those states. These visits made it possible to:

1. Collect much more detailed information regarding current delineation practices and problems than was possible through the use of the form letter.

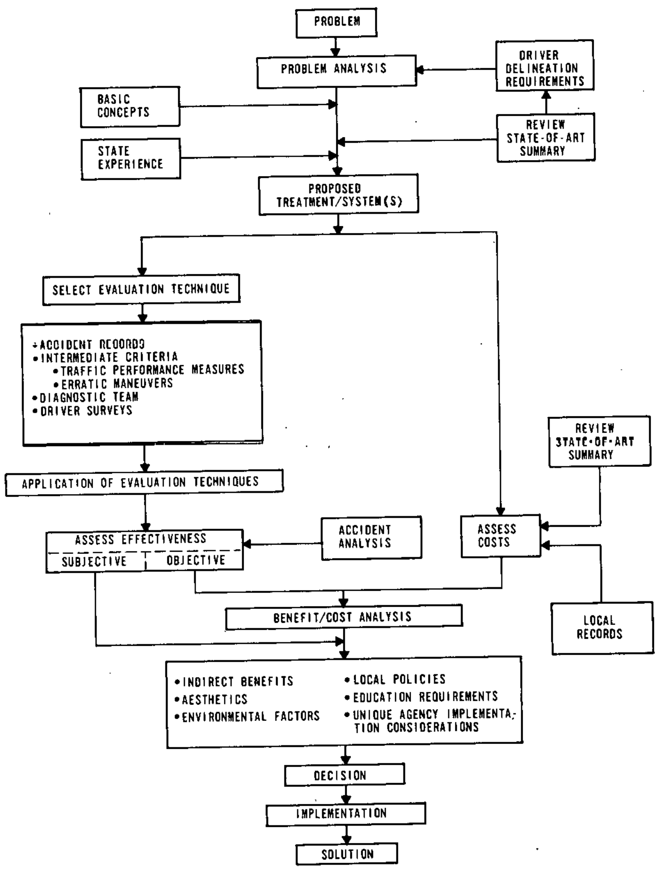

Figure 1. Delineation decision-making process.

2. Explain the program to various highway traffic engineers and obtain their reactions and comments.

3. Determine the type, content, and organization of reports highway engineers would like to see as an end product of this project.

In addition, manuals from seven countries and a code on pavement markings in the ECAFE (Economic Commission for Asia and the Far East) region were reviewed and compared with practices within the United States. The Road Research Laboratory in England was visited to review their extensive research in the delineation area and discuss the rationale for the differing practices in Europe and the United States.

Appendices A, B, C, D, and E represent the state of the art as developed from the literature review, survey of current practices, and discussions with practicing engineers. Some of the major findings are summarized in Chapter Two.

Driver Delineation Requirements. The approach adopted in determining the driver's delineation requirements consisted of an analytical review of the literature, data from the current practices survey, and field observations. This material is also in response to objective 3 of the problem statement.

The two principal aims were to define the purpose of current delineation systems, and to determine the driver's information requirements for all situations, regardless of delineation treatment.

A number of classical or typical situations were identified that collectively exhaust the normal range of maneuvers required of drivers over the usual geometric conditions encountered today. The specific performance or task requirements for each of the delineation situations selected was identified. An information-decision-action (IDA) analysis was used to transform the performance requirements to information requirements; i.e., actions required to effect the desired performance, the decisions required to effect the actions, and information required to elicit the desired decisions and actions were identified.

The IDA analyses and models are included in Appendix A; a discussion of particularly pertinent human factors considerations is included in Appendix B.

Basic Concepts. It is not possible to provide a recommended delineation system for every situation, because of the wide diversity of geometrics, weather conditions, local policies, etc. Hence, a number of "basic concepts" are provided for guidance in selecting delineation systems, and against which proposed delineation systems should be checked. The impetus for this work cuts across objectives 3, 5, and 7.

The concepts include such items as positive vs negative delineation, coding, clutter, overdelineation, advance and near delineation, target value, and relative system strength. Original concepts were postulated on the bases of the state-of-the-art review, discussions with traffic engineers, and rational analysis by the project team. A number of field and laboratory experiments were designed and carried out to test these concepts, and necessary modifications were then made.

The basic concepts are listed in Chapter Two and are reflected throughout the report. The verification studies are described in Appendices F, G, H, I, and K.

Proposed Treatment/System(s). As part of objective 4, efforts were directed toward the effective integration of the previous inputs (*problem analysis,* review of the *state-of-the-art summary,* consideration of the *basic concepts,* and pertinent *state experience*) to lead to the most promising candidate treatments or systems.

Guideline Form II was developed for the systematic integration of the prior inputs and the selection of candidate systems. An example of the use of this Guideline Form is provided in Chapter Two. It is necessarily general, because it must serve for a wide diversity of situations.

Evaluation Techniques. Continuing in Figure 1, and again as part of objective 4, various evaluation techniques were investigated and guidelines for their use were prepared.

The evaluation techniques investigated included (1) accident records analysis, (2) erratic maneuvers, (3) traffic performance measures, (4) diagnostic teams, and (5) driver surveys.

The material was developed through:

1. Study of the application of the various techniques by other researchers.
2. Experience in the testing phases of the project.
3. Rational application of the concepts developed through studying visibility, information processing, driver information needs, and the general characteristics of delineation systems.

Appendix T includes definitions of the evaluation technique procedures, assessment of the major advantages and limitations, and a survey of the types of problems to which each technique has been applied. Guidelines and consideration in designing evaluation studies and the rationale used in selecting the experimental methods for the testing phases of this project are also included in that appendix.

Assessment of Effectiveness. The next step in the methodology of Figure 1, the assessment of effectiveness, inherently overlaps objectives 4, 5, and 6.

The subjective measures include rankings of alternative systems, scaling of these rankings, and assessment of non-accident factors such as comfort and driver acceptance. It is difficult to obtain meaningful numerical representations of these measures, yet they are of major significance in most delineation decisions. Guidelines, consisting primarily of checklists to assure that the most important factors are considered, are presented in Appendix T.

The objective measures include "hard" data, such as statistical assessment of differences in means of variability of various traffic measures and percent change in erratic maneuvers. These data are more clearly related to potential accident reduction and, therefore, to dollar benefits to be derived; but the exact relationships between intermediate criteria and accident reduction are not known. Some attention was directed to establishing this relationship for one situation (horizontal curves) within this study —the results are reported in Appendix Q.

Accident Analysis. An important input to the assessment of effectiveness is the potential for accident reduction. The objective of this phase of the study was to determine the relative number of accidents in which poor delineation is a *probable* factor, and those in which poor delineation is a *possible* factor. Only order-of-magnitude results are reported (see Appendix S), as it is not possible to determine direct relationships between reported accidents and the various delineation treatments, or lack thereof. In fact, little delineation information is reported on any of the accident forms. A 5 percent sample of all the accidents reported in Pennsylvania for a single year was obtained. Each accident record contains 80 information inputs. Sorting on these factors to determine accidents in which poor delineation probably and/or possibly was involved was based on the rational interpretation of the 80 factors by the researchers.

Assessment of Costs. Many cost data were accumulated in preparing the state-of-the-art summary. Unfortunately, local conditions affect the costs so greatly that it is possible to tabulate only guideline figures. These are presented in Chapter Two. An accompanying table was constructed to indicate the costs of various treatments at a few specific situations. These figures can be used in estimating costs of widespread adoption of various treatment policies. All figures must be modified to reflect variations in local costs of materials and maintenance, and environmental factors and traffic conditions that may materially affect the useful life of particular treatments.

Benefit-Cost Analysis. Study in this area was specified in objective 6 of the problem statement.

Appendix E presents a state-of-the-art review of benefit-cost methodologies as applied to highway engineering. More specifically, the most appropriate benefit-cost methodologies to be used for the probable inputs available from the various effectiveness evaluation techniques are described in Appendix T. These guidelines were developed through extensive review of the literature, and after considerable modification to maximize usefulness under the constraints of the input data—particularly the lack of strong relationships between effectiveness measures and dollar benefits.

Other Factors. A number of factors outside the investigative scope of this project also enter into the decision-making process in delineation decisions. These include various indirect benefits, environmental factors (some of these are incorporated into the various guidelines, where they are major determinants), local policies, aesthetics, educational requirements for informing the public of new treatment codes, and implementation considerations that may be unique to the specific agency.

Decision. Guideline Form III, shown in Chapter Two, is to be used for putting all the various considerations previously listed into a usable format to assist the decision-maker in synthesizing these inputs. Preparation of these forms is in response to objective 6 of the problem statement. The format is flexible enough to accommodate the great variety of situations and treatments that can occur singly and in combination. These guidelines were developed by the researchers as a result of their information-gathering activities and experimental programs.

Colored Pavements

The investigation of colored pavements was specified in objective 7, but is not specifically reflected in Figure 1 because colored pavements represent one specific delineation treatment. Studies of the effects of colored pavement on traffic behavior at lane drops, exit ramps, stop approaches, and left-turn slots were conducted and are reported in Appendix K. In general, a before-and-after approach was used, and the measures included spot speeds, lateral placements, action points, and encroachments. Conclusions drawn from the studies are reflected throughout the other sections of the report in the same manner as other delineation treatments.

Because particular interest was expressed in the physical characteristics of colored pavements, tests of the visual characteristics of colored pavement materials under various lighting and environmental conditions were conducted in the laboratory. The two basic dependent variables were the amount of light reflected from colored pavements as compared to standard pavements of asphaltic and portland cement concrete, and the spectral properties of the light reflected. Comments derived from subjective field evaluations are also included. In addition, the skid resistances of several of the test installations on operating highways (with and without glass reflectorizing beads) were determined through the use of a full-scale load friction tester and were compared with the skid resistances of the adjacent portland cement or asphaltic concrete pavements.

In general, then, the research approach was to:

1. Synthesize the information gathered from the literature survey and interviews with practicing traffic engineers in various states.
2. Postulate certain basic concepts of delineation.
3. Field test these basic concepts and conduct a limited number of field studies comparing various alternative treatments.
4. Work with, and assess the effectiveness of, various evaluative techniques.
5. Review and strengthen the postulated concepts on the basis of the field studies.
6. Formulate recommendations for the delineation of a number of "classic" situations.
7. Prepare a set of Guideline Forms to be used by traffic engineers in the decision-making process regarding future delineation treatments.

It was not the intent of this project to develop an entirely new and revolutionary delineation philosophy. It is expected that state highway and traffic engineers will utilize the report results in situation-specific terms—i.e., they will turn to the report when they have a specific curve, intersection, etc., or particular section of road to delineate. The need for delineation may arise because of new construction or because a problem exists for a specific situation.

The major sections of this report (the state-of-the-art summary, the driver delineation requirements study results, etc.) are structured such that they are approachable from the situation-specific standpoint. It is relatively simple to proceed from one section to another and derive the information pertinent to a specific situation—i.e., if the problem is to delineate a rural curve, one can easily assess the delineation requirements for this situation, determine current practices and the state of the art, and locate the project findings and recommendations relevant to this situation.

Throughout this project a continuing assessment of the appropriate level of detail in the investigations and reporting has been required. This report reflects the researchers' judgment of that level. The problem arises from the wide variability in situations to which delineation is applied, the variation in geometric characteristics at these situations, the number of delineation treatments available, environmental constraints, the large ranges of traffic volumes and speeds for which the treatments must be applied, the diversity in current practices, and the variations in driver ability and behavior even when the other variables are held constant.

An attempt has been made to use sound research methods and the best current theory in making all judgments and interpretations. No complete objectivity is claimed, however; and some statements are the obvious result of cumulative reactions by the research staff.

CHAPTER TWO

FINDINGS

The principal findings of the study are presented under three main categories, corresponding to the three major efforts undertaken. First, a state-of-the-art summary is presented; it was developed through synthesis and evaluation of the literature reviewed, current practices observed, and information obtained through discussions with engineers concerned with highway delineation.

The second part presents findings from the laboratory, office, and field efforts related to the basic delineation concepts studied, the field installations and measurements of various delineation treatments, and the in-house development of essential background data.

In the third part, guidelines for the delineation decision-making methodology outlined in Chapter One are provided, with explanatory notes regarding their development and use.

STATE-OF-THE-ART SUMMARY

Appendices A through E constitute the state-of-the-art summary. (Appendix A also includes models for the definition of the driver information requirements. This structure was adopted so that the user will be able to derive the information requirements pertinent to a specific situation and determine the current practices and thinking regarding delineation for these situations from one source.)

Findings from a state-of-the-art summary are, necessarily: (1) statements derived on the basis of careful synthesis of the general literature by the reviewers, (2) references to exceptional or unique current practices, or (3) indications of problems for which solutions are not readily available. Where studies particularly pertinent to the item or problem presented in this summary were conducted as a part of this project, the appropriate appendices are referenced.

Delineation Situations (Appendix A)

In all, nine situations were identified as having sufficiently unique delineation requirements to justify individual attention. These are:

1. Tangent sections.
2. Horizontal curves.
3. No-passing zones.
4. Pavement width transitions.
5. Merging-diverging areas.
6. Turns.
7. Turns with deceleration and/or storage lanes.
8. Stop approaches.
9. Railroad crossings, crosswalks, etc.

Many considerations related to delineation are not amenable to discussion by geometric situations. For example, edge lining may be carried through tangent sections, vertical and horizontal curves, width transitions, etc. Comments relevant to these facets of delineation are also included.

Major points include:

1. Nearly all the states use edge lines on rural two-lane roads (most have warrants excluding edge lines on pavements under 22 ft in width). Studies of the effects of edge lines on accident rates have been limited in scope and duration, but scattered positive results are available and no adverse experiences have been reported to date. Lateral placements and speeds are frequently affected, but potential accident reductions as a function of these parameters have not been established. (See Appendices M, N, O, and Q.)

2. Today's painted longitudinal line patterns are primarily continuations of historical patterns. Various states attempt to simulate these same patterns when installing

raised pavement markers. Little research on optimum patterns has been reported. (A limited study was undertaken within this project; results are reported in Appendix O.)

3. Basic philosophical differences exist as to the proper placement of edge lines on wide two-lane highways (40-ft crown widths)—some claim at 12 or 13 ft from the center line; others say near the edge of the pavement. Texas is experimenting with a painted, traversable median (2 to 4 ft) on these wide roads.

4. Warrants for installation of post delineators on curves on rural highways vary considerably from state to state and even from district to district within a given state. (See Appendices F, G, H, I, M, and P.)

5. Provision of adequate advance warning of the beginning of no-passing zones is a major problem. The yellow barrier lines are adequate information sources once the vehicle is in the no-passing zone.

6. The geometries of pavement width transitions vary considerably, the most critical situations being associated with lane drops. Treatments employed also vary widely, but little research related to evaluation of these treatments is reported. (See Appendices B, G, and K.)

7. Considerations in the delineation treatment of merge/diverge areas cannot be separated from those related to entrance and exit ramps, because the driver information needs are similar yet the situations are distinctly different. Longitudinal placement of advance warning information is particularly critical in the merge/diverge situation. (See Appendices G and K.)

8. Definitive delineation is required in the turn situation because of the relatively high information processing load imposed on the driver by the requirement to make lateral and longitudinal maneuvers under widely varied geometries (intersection angles, presence of deceleration/storage lanes, etc.) while attending to potential conflicts with other traffic. (See Appendix K.)

9. Advance warning is the critical information element in the stop approach situation. Signing does not appear to be entirely satisfactory and investigation of techniques to provide continuous information inputs (such as provided by colored pavements, rumble strips, etc.) is needed. (See Appendices H, K, and P.)

Human Factors (Appendix B)

The review of the human factors literature yielded findings of two types: general operating guidelines for research, and observations that have direct bearing on the design of delineation systems.

Research guidelines resulting from the study were as follows:

1. The analysis of the various roadway situations in terms of the information needed by the driver, the alternatives available to him, and the maneuver components involved revealed a substantial number of common elements. The existence of these elements not only allows one to describe the wide variety of different roadway geometries in terms of a relatively small number of situation models, but also suggests that individual delineation treatments may appropriately have wide applicability.

2. The problem of obtaining a valid, reliable, and economically feasible criterion of effectiveness against which to evaluate changes in the driver/vehicle/roadway system has no universal solution. Accident data and operations measures (under rural, low-volume conditions) are difficult to obtain, hard to appropriately standardize, and relatively insensitive to small changes. (See Appendix T.)

3. The development of intermediate criteria based on the notion of changes in the average magnitude of deviations from an ideal path, although promising from the point of view of ease of measurement and over-all sensitivity, fails for lack of agreement regarding the "ideal path." A promising alternative appears to be the use of a "reliability concept," where reduction in the variability in driver behavior, rather than the average magnitude of the change per se, is the measure. (See Appendices Q and T.)

4. The conceptualization of the driving task that appears to be potentially most useful for guiding the study of delineation system design is based on the idea of a "field of safe travel." In this context the role of delineation in *any* situation is to keep the driver appropriately advised as to the confines of that field. (See Appendices G and I.)

5. The quality of driver performance will be reduced if too much information is given too fast, if actions must be accomplished in very rapid succession, or if the information provided leaves the driver in doubt regarding precisely what action he should take. Applications of delineation treatments must be designed to lessen the effects of these conditions by providing advance information and/or by deliberate and careful use of redundancy. (See Appendices G and H.)

Design observations resulting from the study were as follows:

6. The vast range of human capability in vision and information processing, and the complexity of the interactions with changing environmental conditions and variations in target characteristics, make any attempt to derive universally applicable design principles impractical. It is possible, however, to point out certain general factors that should be taken into account when designing a delineation system, as follows:

(a) The detecting power of the eye (sensitivity) is generally both more important and more easily capitalized upon in the driving situation than is the resolving power (acuity). (See Appendices G, J, and K.)
(b) Under conditions of low illumination the contrast between a target and its background is more influential in detection than is the absolute brightness of either. (Note that although delineation treatments are fixed, backgrounds can vary widely.) (See Appendices F, G, and H.)
(c) In the process of controlling his vehicle, the driver must make estimates of speeds and distances; the ease and/or accuracy of these judgments is enhanced by the presence of reference points that can be supplied via delineation. (See Appendix I.)
(d) The ability of the driver to make reliable discriminations among the messages associated with

various delineation treatments may be impaired if the number of message categories employed becomes greater than seven. (See Appendices G and H.)

Delineation Treatments (Appendix C)

A summary of the findings relevant to the materials, maintenance, environmental effects, and cost aspects of delineation treatments is presented in Appendix C. The principal treatments are:

1. Pavement markings.
2. Post delineators.
3. Raised pavement markers (RPM).
4. Colored pavements.
5. Rumble strips.
6. Curbs.
7. Indirect methods.
8. Systems of treatments.

Findings from the review of the literature and current delineation practices include:

1. Standard paint, with or without reflectorizing beads, is the most commonly used pavement marking material for rural highways. Thermoplastics are gaining acceptance in urban areas where there are high volumes, and for special situations. The relative cost of thermoplastic striping (approximately 15 times that of paint striping) has discouraged general use on rural highways.

2. Post delineators of various forms and shapes are used widely throughout the United States, for they are effective during nighttime and during inclement weather when standard pavement markings are ineffective. However, post delineators are used as a supplement to, and not as a replacement for, standard pavement markings.

3. Although a wide variety of raised pavement markers is being used, no single marker has been developed that is suitable for both daytime and nighttime. At least two firms are developing raised pavement markers claimed to be suitable for areas requiring snow removal, but adequate field evaluation is not yet available.

4. Raised pavement markers cost about twice as much as paint during the first year, but the costs are about the same when averaged over a 10-year period. Life expectancy of the raised pavement markers is 3 to 10 years on the average, depending on type, traffic volumes, environmental conditions, etc.

5. Widespread use of colored pavement has been impeded by the following factors:
   - (a) Lack of agreement on color use.
   - (b) The colors are not effective at night, and tend to fade with time.
   - (c) The materials are expensive.
   - (d) Effectiveness as a delineation treatment has not been adequately demonstrated. (See Appendices K and L.)

6. There are no "standard" rumble strips; several types have been used in experimental programs and in limited applications.

7. Curbing per se does not provide good delineation unless supplemented with an additional treatment, such as reflectorized paint, curb-mounted reflectors, or low-intensity lights. Due to their nearness to the traveled way, these supplemental treatments are subject to road film, with subsequent diminishing of their reflectivity. Low-intensity lights are probably least affected by environmental conditions, but are more costly than the other treatments.

8. Indirect delineation cues, such as guardrails (especially when reflectorized), fences, or lines of utility poles, can be valuable supplements to standard delineation techniques. These cues can be misleading, however, if their alignment unexpectedly deviates from that of the roadway.

Delineation Practices in Other Countries (Appendix D)

This portion of the state-of-the-art summary was derived primarily from manuals, and as such represents primarily statements of standard practices in other countries; the other portions of the report tend to emphasize new and/or unique practices, on the assumption that readers are familiar with the standard practices in the United States.

1. As a result of interviews with visitors to and from European countries and the limited literature survey conducted, it is believed that delineation receives relatively more attention in those countries.

2. Several countries, including England and Germany, use only white for pavement markings. Most other countries use a two-color system (white and yellow).

3. No country has a completely consistent delineation system in terms of meanings for pavement line color and/or line shape.

4. One of the more noticeable differences in marking practices in other countries is the widespread use of very wide (12 in., and even up to 30 in.) pavement stripes. Frequently, these stripes are used in addition to contrasting shoulder treatments and are considered essential safety features.

5. Markings between through lanes and speed change lanes are generally more pronounced than in the United States. Several countries use wide dashed lines and carry them throughout the length of acceleration and deceleration lanes.

6. One of the more noticeable practices in England is the coded patterns of broken lines. England uses a single-color system, which makes it necessary to vary the type of broken lines to meet the several traffic situations. "Warning" lines are used extensively; these lines consist of longer segments and shorter gaps than the standard lines and are used to designate a degree of restriction between that of normal lines and no-passing zones.

7. Thermoplastic lines are used much more extensively in Europe. The initial cost, as compared to painted lines, is approximately 3 to 1 in England—considerably different from the 15-to-1 ratio in the United States.

8. Several different types of post delineators are used in other countries, with some designed to provide both

daytime and nighttime visibility. In general, the application is not as widespread as in the United States.

9. With few exceptions, raised pavement markers are used only as a supplement to standard pavement markings. The application is not widespread in any country except England, which uses the "Catseye" road stud extensively.

10. No indication of the use of colored pavements has been found, and although it seems probable that rumble strips and curbs are used in other countries, no reports on these treatments were available.

Cost Effectiveness (Appendix E)

A summary of literature related to the general methodologies of benefit-cost analysis and the evaluation and quantification of benefits of highway projects is presented in Appendix E.

1. There are few existing cost-benefit models that can be applied directly to the evaluation of improvements in highway delineation systems. The "traffic conflict" method proposed by Perkins (*377*)* for measuring the effectiveness of some traffic engineering changes seems to indicate an area in which more work should be done. If the occurrence of different types of accidents can be quantitatively related to the various types of traffic conflicts, it follows that changes in accident rates can be predicted from changes in observed traffic conflicts. (See Appendix Q.)

2. Benefit-cost analysis should be an aid to the decision maker—it should not be the sole basis for decision-making.

3. There is no method reported to eliminate or even reduce the uncertainty involved in the estimation of future costs and benefits.

4. It is not reasonable to insist that every benefit pertinent to the cost-benefit analysis be quantified. This insistence will lead to either of two types of error:

   (a) To exclude from consideration all benefits except those that are capable of quantification.

   (b) To use a meaningless quantification of nonquantitative benefits—e.g., the use of arbitrary numbers to represent pain and fear in accident cost studies.

5. There are indications that "present worth of the benefits minus costs" is the best of the criteria available to evaluate various delineation treatments.

6. Estimation of the costs of various treatments/systems is reasonably straightforward. Estimation of the benefits is the "bottleneck" in the application of benefit-cost analysis to highway delineation studies.

INVESTIGATIONS AND STUDIES

Conceptual Studies

In the conceptual studies, the emphasis was on development of delineation "rules" that can be applied in many situations and can be used as a preliminary evaluative checklist when considering new treatments or development of new delineation systems for wide application.

* References in italics are to entries in Appendix V, "Bibliography."

Overdelineation

There is concern that overdelineation—i.e., either an excess in quantity (e.g., close spacing of post delineators) or quality (e.g., brightness of post delineators) of delineation—may encourage drivers to maintain speeds in excess of "safe" speeds. The drivers may be led to believe that because they can detect a high-intensity post delineator at a distance exceeding 4,000 ft, they can "see" the road for this distance.

A study was conducted to determine if there was a relationship between the brightness of the post delineators along a section of four-lane divided highway and the average vehicle speeds. (See Appendix F.)

The section of highway selected for the study had a good concrete surface; the test site was on a long gentle downgrade. Thus, drivers were free to choose their speed with no constraint from vehicle power capability or rough surfaces. The horizontal alignment consisted of tangent sections and several horizontal curves sharp enough to require some speed decrease for proper negotiation. The test site was located in a rural area; there were few extraneous lights or other distractions. It can be presumed that vehicle speeds were determined largely by the driver's perception of the roadway path.

Spot speed data were collected at three locations for two conditions—i.e., "bright" where the delineators were washed just prior to data collection, and "dull" where the delineators were filtered to reduce the brightness to about one-half.

No statistically reliable differences were found in comparisons relevant to the intensity-speed relationship. It seems, then, that the drivers were not making speed decisions on the basis of the distance over which they could see the post delineators. Rather, it appears that they are using information sources, including the post delineators, in the near portion of their nighttime field of view to make speed decisions. This latter conclusion is supported by experimental work conducted by Rockwell (*145*), and other field experiments of this project.

Personnel of the California Division of Highways report that speeds have increased during fog conditions after the installation of raised pavement markers. Data are not available to support this contention, but there is nearly universal agreement that the speeds do increase.

Hence, it is concluded that driver behavior will not be significantly affected by the "strength" of far delineation, but probably will be affected by "near" delineation under adverse weather conditions—e.g., fog or heavy rainfall.

Still unanswered are more subtle questions regarding the effects of strong "far" delineation on the driving task—i.e., although speeds are not affected, drivers may be more at ease with knowledge of the roadway path over an extended distance. Project personnel did favor the brighter delineators in the test section. At any rate, decisions on replacement and washing cycles for reflective devices must be made on the basis of their contribution to driver ease rather than field-measurable driver performance.

Coding and Information Value Study

Among the more obvious but nonetheless important problems uncovered during the course of this project was that the lack of standardization within and among states in delineating roadway situations leads to considerable confusion on the part of the driver. The same treatment and/or system is often indiscriminately applied to a wide range of situations. Post delineators, for example, are commonly used in situations (e.g., roadside ditches, culverts) that require simply passive observation and awareness on the part of the driver, and in others (e.g., ramps, curves) that may require immediate transitional maneuvers.

Engineering attempts to provide discriminable information through the coding of delineation treatments have met with mixed success. Surprisingly, some of the more promising conceptual systems have failed when subjected to field test. In reviewing those studies which evaluated such systems as ineffective, several methodological deficiencies were identified. One of these concerns the choice of an appropriate criterion variable; e.g., if one is interested in whether or not a particular treatment enhances the driver's ability to identify a roadway situation, then measures of lateral placement or points of encroachment, etc., should not be used to gauge effectiveness. (These measures, of course, may be appropriate to evaluate the effectiveness of the treatment in providing desirable "pathway" information.)

Another deficiency involves classical before-after field test designs where the change consists of the installation of a treatment. Unless the intention of the experimental system is communicated to the driver, judgments of effectiveness are inconclusive. In some instances, despite a lack in communication between the engineer and the driving public, a system may be judged effective because it has intrinsic value; i.e., there is an inherent message in some system attribute that results in the desired behavior.

The problems discussed in the foregoing deal with discriminability in situation identification, and the dependency of measures of effectiveness on the nature and quality of the delineation information provided to the driving public by the engineer. One environmental factor related to both the "information" and discriminability issues is the immediate background and surround of the area in which a delineation system may be employed. In many cases, house lights, luminaires, other delineation, etc., "cluttered" the primary delineation system and degraded its pattern, code value, contrast, etc. Because all of these factors seem to operate simultaneously, a decision was made to design a comprehensive study that examined the information-decision behavior of the driver in a laboratory environment where control could be exercised over the variables of interest and possible contaminating influences. (See Appendix G.)

The purposes of this comprehensive study were: (1) to assess the effects of information and learning on situation identification; (2) to assess the relative effectiveness of selected codes, treatments, and systems for a number of situations; (3) to evaluate the degree of resistance to environmental clutter of these codes, treatments, and systems; and (4) to characterize the specific cue utilization that ultimately results in situation identification. An additional, but subordinate, goal was to provide an evaluation of concepts that cut across these problem areas (e.g., dual vs single reference lines, color vs pattern).

The experimental procedure for all the studies was designed to simulate the driving situation where the driver previews the roadway ahead (on a sampling basis) in order to have knowledge of upcoming maneuvering requirements. The stimulus materials for the study consisted of slides of actual roadway scenes, some of which were unaltered photographs and some of which were manipulated in order to control: (1) delineation and non-delineation cues (such as guardrails), and (2) background clutter of various types. These stimuli were presented to test subjects in three groups that had been given differing amounts of "information" before the study. The presentation apparatus consisted of a conventional auto-focus slide projector, which was integrated into a system containing a large shutter and electronic activation and timing component so that exposure time and inter-trial interval could be accurately controlled.

The results of that portion of the study related to assessment of the value of prior information regarding the various codes used (color, shape, etc.) showed that although the "information" group had a higher mean percentage of correct identifications across all situations, the difference between the groups was not statistically significant at the 0.05 level. However, when the data are separated with respect to the situation involved, it was shown that the "information" group performed significantly better (0.05) for the lane drop and stop approach situations, but not for the ramp and curve geometries. One implication of the results of this portion of the study is that any colors used for coding should be used in a unique fashion if the full benefits of coding are to be realized.

The analysis of treatment effectiveness used only data from the "no-information" group because it was believed that this group would be more representative of the average driver population. In the case of treatments, the analysis was accomplished separately for each situation, with the following results:

1. *Exit Ramp Treatments.* The data suggest that the use of blue ramps was an effective treatment, even though the subjects were not informed that blue was a code related only to ramps. The generally greater effectiveness of blue treatments, as opposed to amber treatments, perhaps reflects the fact that amber was used for a number of other situations whereas the blue treatments could be used to uniquely identify the ramp situations.

2. *Curve Treatments.* The post-mounted shaped delineator devised by the research team as an experimental treatment (essentially an arrow pointing in the direction of the upcoming curve) resulted in 100 percent identification performance. Inasmuch as the subjects had no prior information about the shape code, these results indicate that the treatment has high intrinsic informational value. Even a single shape post, used to simulate reduced visibility conditions, resulted in 83 percent correct responses, a performance level that puts it among the top three of all treatments used. With the exception of the shapes, those

systems that included an RPM (raised pavement marker) center line produced the most accurate identification performance.

3. *Lane Drop Treatments.* Identification performance for all lane drop treatments was relatively poor. The best treatment (resulting in only 44 percent correct identifications) was amber raised pavement markers placed on the lane drop taper. This was followed by a system using amber pavement arrows and amber shape arrows in combination.

4. *Stop Approach.* With one exception, those systems that included a crystal-colored component (either center line or edge treatment) produced poorer identification performance scores than did those systems composed entirely of red. Further, the systems involving dual lines of reference (i.e., edge and center line treatment) did not produce significantly different performance than did the systems utilizing only a single reference line.

The effects of clutter were determined primarily by applying a ranking device that took into consideration the "goodness" of the system in both the pure and the cluttered states. The evaluation was made in terms of the change in within-situation rankings when a comparison was made of the pure system ranking (i.e., from the treatment analysis) and the rankings that resulted from application of the composite rank index.

In general, the systems used showed a high resistance to clutter. However, several factors, such as learning during the experimental session, confounded the results to some degree. The results suggest that crystal post delineator treatments were more vulnerable to the effects of clutter than were amber post delineators when used on curves. The effects of clutter were not discernible for the lane drop treatments, probably because the performance on the pure systems was at or below chance expectancy, hence further degradation was not measurable. Neither did any of the stop approach treatments used show statistically significant degradation under clutter conditions. Finally, of the ramp treatments used in the study, the data indicate that in a cluttered environment a painted gore will result in better performance than will RPM's on the gore. However, it should be noted that the gore areas in the stimuli used were newly painted.

With regard to cue utilization, the results suggest that attention to locational factors (including typical geometric and pattern cues) serve to discriminate between good and bad performance in situation identification. The implication of this finding is that if color is to be employed as a code for situation identification, it would be advisable to consider its role as indirect or second-order—at least under the current situation where a color can provide several different messages.

Target Value Study

The purpose of the target value study was to evaluate the target value or stimulus strength of a number of stop approach treatments. (See Appendix H.) The justification for such a laboratory study was that perceptual effectiveness constitutes a necessary (but not sufficient) condition in the determination of operational effectiveness. In addition to requiring less time than a field study of similar scope, the laboratory setting permits control of the many environmental variables that influence perception and are not easily controlled in the field. The binocular rivalry technique permits detection and measurement of perceptually relevant differences between targets (systems) and is, therefore, a meaningful way in which to obtain estimates of potential system effectiveness.

The stimuli used for the study were photographs of a number of stop approach systems that had been installed on a temporary basis on a closed section of two-lane rural highway. The treatments involved in the study were post-mounted reflective delineators and raised pavement markers. These treatments were varied with respect to spacing and color (red and crystal). One other independent variable was the inclusion or exclusion of the conventional STOP sign.

A three-channel tachistoscope was used to present stimulus pairs (one photograph to each eye) to subjects for short-duration exposures (0.5 sec). It should be noted that the subjects were not aware that they were being presented with more than one stimulus. After separate examination of each stimulus the subjects then responded by choosing which member of the pair they had seen. According to the binocular rivalry paradigm, then, that element of the stimulus pair that had the greater perceptual effectiveness (or target value) would be perceived and reported as the stimulus seen. For each pair of photographs only a single element differed (i.e., color, spacing, number of reference lines, etc.) Hence, evaluations could be made at the element rather than the system level.

Presence vs absence of STOP sign comparisons indicated that the STOP sign acted as a significant perceptual cue, regardless of which system was used (as would be expected). However, the strongest effect of the STOP sign was noted when it was used with those systems in which no edge delineation was involved and it was, therefore, the only edge cue.

In the experimental situation, the difference between 80-ft and 40-ft spacing of RPM's was not significant. This does not necessarily mean that there would be no surprise effect in the dynamic situation. A geometric spacing of posts (whereby the spacing decreased as the STOP sign was approached) proved to be a more dominant pattern than the conventional (i.e., 200-ft) spacing. This is probably attributable to the perceptual "grouping" of delineators close to the STOP sign when the geometric spacing is employed.

The dual-reference (two-line) systems were shown to be dominant over single-reference (one-line) systems, a result that obtained regardless of color and spacing factors. It would appear that the "tunnel" effect created by the dual-reference systems provides both a better spatial orientation for the driver and a convergence on the focal point —the STOP sign.

In examining both dual-reference comparisons and single-reference comparisons, no significant differences were observed between RPM's and post delineators or between red and crystal. Based on these data, admittedly a static situation, there is no single treatment or color effect that would merit any change from the current warrants for stop approaches—at least in those situations where the STOP sign is visible (i.e., not hidden by vegetation, curvature of the roadway, etc.)

Positive/Negative Delineation

Delineation systems can be classified as either positive, or positive/negative, depending on the intent of the message or messages to be conveyed by their component treatments. A *positive* system is one that provides guidance information concerning where a driver may safely drive, whereas a *positive/negative* system employs the guidance function and, at the same time, marks locations where hazards exist, thus indicating where drivers may not drive. The combined system has been criticized on two counts: (1) the negative components are ineffective in that they fail to convey the "hazard" message, and (2) the net effect on the system is to degrade the pattern of the positive elements. A controlled night field study was designed to test the validity of these criticisms. (See Appendix I.)

The assessment of negative delineation has proven difficult in the past because there has been no firm basis for comparison; i.e., failures (accidents) are almost always reported and available, whereas little is known regarding successes (avoidance of accidents). In the absence of such exposure data, failure frequencies are meaningless. This experiment was designed to obtain the necessary rate information without influencing the subject's normal attention to delineation in any way.

Under a "reaction-time" cover story, subjects were instructed to drive a closed section of a rural two-lane highway at a constant speed of 35 mph. They were told that at some point during their trip they would encounter oncoming traffic and that an improper passing maneuver would be initiated by an opposing vehicle. The presence of an adjacent pair of headlights (i.e., an oncoming vehicle passing in their lane) was to be their signal to take evasive action by pulling completely off the road. They were informed: (1) that the "reaction time" measure began with the onset of headlights and terminated when the vehicle was completely stopped and off the road, and (2) that in order to get reliable measures they would have to make four runs.

The passing vehicle was simulated by means of a 2 × 4-in. wooden frame construction supported by a bicycle wheel assembly and side-mounted to the trailer hitch of a van. Conventional sealed-beam headlights were mounted in appropriate relative positions on this frame and were activated by the experimenter in the van when the subject vehicle reached a predetermined point. The subject's arrival at the proper point was communicated to the van driver through a hidden light signal triggered by the subject vehicle's passage over pneumatic tubes. The vehicle speeds and the placement of the triggers forced the subjects to take a path that carried them into one of two target areas. In these target areas, a simulated roadside obstruction was delineated in one of four ways: (1) no delineation; (2) amber, high intensity; (3) amber, low intensity; and, (4) clear, low intensity. These conditions, the target area selected for any given run, and the position of a decoy vehicle (a feature used to avoid premature reactions based on learning from earlier trials) were arranged in a Graeco-Latin Square design.

Breakaway safety features were employed in the passing vehicle simulator and the target area posts in order to accommodate the collisions with the simulator, which might occur, and collisions with the posts, which were expected. The frequency of post hits for a given delineation condition was the dependent variable of interest in this study. A post-experimental interview was conducted with each of the 24 subjects in order to characterize the typical driver's knowledge and conscious processing of roadway codes and provide a basis for interpretation of the performance data.

In general, the performance results suggest that the first criticism (i.e., that negative delineation fails to convey a "hazard" message) is valid, and that the second (i.e., the net effect of the negative is to degrade the positive pattern) is invalid. Judging from the interview data it would appear that there is little in the way of intrinsic or cultural value in the meaning of amber, despite its widespread use. Although a two-thirds majority reported that they were not confused by the presence of amber, more than one-half of the drivers failed to associate amber with a hazard and more than one-half failed to notice it even though they drove a collision course with amber reflectors on two of their four trials. Although no controlled assessment of pattern degradation was attempted in this study, driver behavior under the differential visibility systems (high and low reflective intensities) showed no reliably different performance effects.

Treatment Studies

Field installations were made to compare alternative treatments for specific situations. Various types of data, appropriate to the treatment/situation being tested, were collected and statistical analyses were used to determine differences.

Colored Pavements

Colored pavement material, similar to asphaltic concrete except that a synthetic resin is used as a binder, was placed at a total of 28 sites—twelve stop approaches (red), nine exit ramps (orange), five lane drops (yellow), and two left-turn slots (green). In an effort to improve nighttime color visibility, reflectorized glass beads were used at a few sites. Details of the installation dimensions, specific types of data gathered, and statistical analyses can be found in Appendix K.

Specific conclusions arrived at as a result of these studies include:

1. Mean speeds on the approaches to STOP signs were reduced when the red-colored pavement was installed.

2. The use of yellow-colored pavement to delineate a lane drop area did reduce the number of encroachments on the restricted area from that observed when double yellow lines or zebra striping were used. Lateral place-

ments within the through paths were not noticeably affected.

3. Orange-colored pavement on exit ramps did influence vehicle speeds. In most cases, the speeds were higher after installation of the colored pavement—this may indicate a higher degree of driver confidence. In a few cases, where the exit ramps were quite sharp, the speeds decreased.

4. In all of the foregoing situations colored pavement did not materially influence traffic behavior at night. This was to be expected, because the colors, even when reflectorizing beads were applied, could not be distinguished readily at night.

General observations (*not* substantiated through numerical data) relevant to the colored pavement studies are:

1. The colors were bright, and even startling, when new; but with passage of time (approximately nine months, including the winter) there has been some fading. The yellow, particularly where contrasted with portland cement concrete roadways, has taken on an off-grey appearance. The yellow pavement is more noticeable when contrasted with asphaltic concrete pavements, but more as a function of change in grey-scale than as a yellow pavement. The orange pavement has dulled considerably, and although it has a different appearance from the adjacent pavements, it lacks "impact." The reds and greens have held up best of all and are still identifiable, although the intensity is considerably diminished from the original emplacement.

2. The nighttime color visibility was marginal when the pavements were new. Nine months, including most of one winter season, after the installations, the colors are barely identifiable by the researchers. Again, a "change" in pavement is noticeable and may be of some benefit, but the color code has certainly been lost. (Further comments on the visibility characteristics of the pavements are included in Appendix L and later sections of this chapter.)

3. The colored pavement material is about eight times as expensive as standard asphaltic overlays and requires careful selection of the aggregate and carefully controlled installation procedures. Use of red-colored pavements may have merit as an additional attention-getting device at locations where there are large numbers of daytime run-the-STOP-sign accidents. Some benefit may also be obtained at night in this situation. It appears that solid yellow areas are more effective in preventing encroachments than double yellow lines or zebra striping. This seems related to "strength" rather than the material itself, and it is suggested that heavier zebra strip pavement markings be used if there is an encroachment problem. All in all, it seems that colored pavements will be useful and economically justified under only very exceptional conditions, and in unique applications. Widespread adoption as a standard treatment does not appear to be feasible.

Comparison of Alternative Delineation Treatments on Rural Horizontal Curves

The objective of this study was to compare the effect of painted center line markings, post delineators, raised pavement markers, and combinations of these treatments on traffic behavior. Details of this study are reported in Appendix M. The study was divided into two phases. In the first phase, six patterns of post delineators and a null case were tested. In the second phase, raised pavement markers and painted center lines were compared, with and without post delineators. The specific treatments were:

Phase I:

1. No delineators (null case). A weathered painted center line existed at the site, but no delineators were placed along the roadway for traffic guidance.
2. Right edge only. Crystal delineators were placed along the right edge of the roadway in the direction of travel.
3. Both edges, crystal. Crystal delineators were placed along left and right edges of the roadway in the direction of travel.
4. Both edges, amber and crystal. Crystal delineators were placed along the right edge; amber delineators along the left edge in the direction of travel.
5. Outside of curve, crystal. Crystal delineators were placed along the right edge of the roadway except at right curves. At right curves the delineators were placed on the left edge of the roadway.
6. Outside of curve, revised spacing. This pattern was the same as No. 5 except that the spacing between the delineators was doubled.
7. Outside of curve, amber. Crystal delineators were placed along the right edge of the roadway except at right curves. At right curves amber delineators were placed on the left edge of the roadway.

Phase II:

8. Raised pavement markers and post delineators. Yellow RPM's were placed to simulate a single center line and the post delineators were placed in Pattern 7.
9. Raised pavement markers. The post delineators were covered and the RPM's were left in place.
10. Freshly painted center line. The RPM's were removed and reflectorized yellow paint was applied for the center line.
11. Freshly painted center line and post delineators. Post delineators in Pattern 7 were installed, in addition to the painted center line.

The treatments were applied over a 1.6-mile section of a rural state highway in Pennsylvania. Vehicle speed and lateral placement data were collected for each of the treatment conditions at each of two consecutive curves. The speed data were collected in a series of eight 100-ft traps centered on the curve. Data were collected for free-flowing traffic in both directions, at night and in good weather.

Analyses of these data reveal that:

1. Vehicular speeds within the curves are insensitive measures for evaluating various delineation patterns. The mean speeds and variances were essentially the same for all the patterns in both Phases I and II.

2. Lateral placements (and speeds) were not meaning-

fully different for any of the seven patterns in Phase I (including the null case).

3. Lateral placements, and especially the variance, were affected by changes in the delineation treatments in Phase II.

4. The variance of the lateral placements was reduced in comparing a freshly painted center line with the original weathered center line. (No delineators, in either case.)

5. The lateral placement variance was further reduced in the presence of raised pavement markers (over the freshly painted center line treatment).

6. Addition of the post delineators to the freshly painted center line tended to increase the mean lateral placement, as measured from the center line. The variances of the lateral placements were also reduced. When post delineators were added to the RPM pattern, no change in mean lateral placement was noticed (these two treatments provided the greatest values of mean placements of the eleven treatments investigated). In three out of four cases, variance in lateral placement was decreased.

Over all, then, Pattern 8 (RPM's and post delineators) was the most effective in terms of maximizing mean lateral placement from the center line and minimizing variance in the lateral placements. Major improvements were noted when the center line was "strengthened"; the effects of the post delineators were minimal and not entirely consistent.

Raised Pavement Markers on Rural Horizontal Curves

Raised pavement markers (RPM's) are used extensively for lane lines and left edge lines on median-divided, multi-lane highways. The study described in the previous section, and in more detail in Appendix M, included the installation of RPM's as an alternative treatment to post delineators at horizontal curves on two-lane rural highways. This study was conducted to further investigate the effects of RPM's on driver performance and, in particular, to consider their effectiveness in combination with painted edge lines.

Four delineation test configurations were installed at a horizontal curve with a radius of 288 ft and a length of 440 ft. (See Appendix N.) The four configurations were:

1. Weathered center line and edge lines.
2. Raised pavement markers installed as a double yellow center line (throughout the curve and approximately 150 ft on each approach).
3. Freshly painted white edgelines with the RPM's.
4. Freshly painted yellow center line and white edge lines; RPM's removed.

A double row of low-intensity yellow markers on 3-ft centers with 4 in. between the rows was used to simulate the center line; pairs were alternately reflectorized and nonreflectorized.

For each of the treatment conditions, spot speeds at the approach to and within the curve, and vehicle placement within the curve, were collected.

The results of the experiment were:

1. Speeds of passenger vehicles were not materially affected by the four delineation treatments studied.

2. Vehicle lateral placement is sensitive to the delineation treatment. Configuration 3 (RPM's and painted edge lines) produced the most desirable effect—vehicular placement variability was reduced and drivers tended to adopt a more central position in their lane. By the same criteria, use of the RPM's alone was next best. The presence of the painted lines provided considerable improvement over the initial condition, in which the center line and edge lines were very poor due to wear and weathering.

3. The visibility of the markers at night was excellent, especially during rain. The pattern employed was adequate in simulating a double yellow line, both day and night.

4. Raised pavement markers, placed as they were in this study, are approximately four times as expensive as standard paint lines. The cost could be reduced somewhat by using a slightly larger spacing.

5. As another study in this project (Appendix Q) indicates a strong correlation between lateral placement variability and accident experience, it would seem advisable to install RPM's on curves that have a high accident history, even though they are more expensive than paint lines. If accidents are reduced significantly at these trial installations, serious consideration should be given to wide-scale installation of RPM's at horizontal curves in two-lane rural highways.

6. The addition of edge lines to the RPM center line treatment did not materially improve traffic performance. Hence, the use of edge lines at isolated treatment locations should be dependent on whether or not they are used on the adjacent sections of highway.

Center Line Marking Patterns

The standard center line paint pattern for rural roads is 15 ft of line segment to 25 ft of gap (3/5 ratio). As there seems to be no scientific basis for this pattern, but rather a continuation of historical usage, a study was initiated to determine if a more economical pattern could offer adequate delineation. (See Appendix O.)

Several patterns were evaluated subjectively, and a test pattern of 5 ft of mark to 35 ft of gap was chosen for installation. It was hypothesized that there would be no significant difference between the test pattern and the standard pattern in terms of vehicle speed and lateral placement, and, therefore, the test pattern could result in a substantial saving in paint costs.

A site approximately 3,000 ft in length, consisting of a tangent section with a slight crest vertical curve at one end, was selected. Although passing was legal throughout the entire section, the slight vertical curve did create a condition whereby the length of center line visible was restricted for traffic in one direction.

Data were collected for the following five treatments:

1. Null condition; badly weathered center line and edge lines.
2. Test pattern with no edge lines.
3. Standard pattern with no edge lines.
4. Standard pattern with edge lines.
5. Test pattern with edge lines.

Speed and lateral placement data were collected during the daylight and nighttime hours for each of these conditions. Speed data were collected by the use of radar meters, whereas a segmented tape was used to collect lateral placement data.

Conclusions were:

1. Although statistically significant differences in the mean speeds did occur over the various treatments and day/night conditions, no discernible pattern was evident.
2. There were no significant differences in the lateral placements, regardless of the center line treatments.
3. Higher speeds were observed with the addition of edge lines to both patterns; decreases in the variabilities of speeds and lateral placements were also noted.
4. It was found that no correlation existed between speed and lateral placement of individual vehicles.

It is believed that the test section was too short to provide conclusive results. Although there were no meaningful changes in the traffic performance measures observed, it was noted that the test center line pattern was "weaker" in appearance. However, this pattern is not radically different from the standard pattern used in England (3 ft mark to 27 ft gap), and adoption would reduce paint material costs and open the possibility of a warning code intermediate between this "weak" pattern and a solid line—e.g., a pattern such as 20 ft mark to 10 ft gap could be employed on approaches to hazardous areas or on the approaches to no-passing zones. This "warning line" concept is also used widely in England.

Stop Approach Treatments

The purposes of the stop approach field study were to assess the effectiveness of selected post delineator systems in terms of longitudinal tracking performance (speed profiles in the stop approach area), and to validate a laboratory methodology (see Appendix H) devised to short-cut the selection of performance-effective systems. See Appendix P for a more detailed discussion of the over-all study.

Specifically, the study involved spot speed comparisons across four delineation conditions at the same site. The systems selected for study were:

1. Base condition, no delineators.
2. Red post delineators, geometric spacing (defined in following paragraph).
3. Red post delineators, conventional spacing (i.e., constant spacing at 200 ft).
4. Crystal post delineators, geometric spacing.

In the geometric spacing, the first post delineator was placed 10 ft from the STOP sign. Successive delineators, working back from the STOP sign, were then placed at a distance double the previous interval, with the restriction that no spacing would exceed 200 ft—i.e., the successive spacings were 10, 20, 40, 80, 160, and then 200 ft for the remainder.

The spot speeds were taken at points 200 and 500 ft before the STOP sign. Comparisons of the mean spot speeds among the four treatments revealed a significantly lower mean speed for Treatment 4 at both the 500-ft and 200-ft stations. In addition, the mean speed under Treatment 3 was lower than for either Treatment 1 or Treatment 2 at the 500-ft station.

The comparisons of variabilities indicated no statistically significant differences among the four treatments. Small differences were noted, but they did not show any apparent trend. On the average, the variances for Treatment 4 were lower than for the base condition (Treatment 1).

Although it might be suspected that Treatment 2 would have the strongest visual impact because of its uniqueness, subjective evaluations in the field indicated that Treatment 4 had more impact—possibly due to the higher intensities of the crystal delineators. In addition, red delineators are commonly used as driveway markers, and consequently are not as attention catching.

Background Data Development

In a few instances it was necessary to develop data on specific characteristics of the delineation treatments. The data either were not available in the literature, or required a major restructuring to be of use. Findings from these efforts are listed in the following.

In addition, two studies of a general nature were undertaken—one to attempt to validate the relationships between intermediate traffic measures and accident experience, and the other to assemble accident data in a manner meaningful to this project. Findings from these studies are also reported in this section.

Evaluation of the Visibility of Reflective Devices

It initially was felt that, inasmuch as the physical data on reflectivity provided by manufacturers cannot always be translated directly into visibility distances, further comparisons of various delineation treatments might be of value to the operating engineer. Upon closer investigation, however, it became obvious that units and test methods were not the sole difficulty. Many laboratory and field studies relative to the visibility of paint, beaded paint, raised pavement markers, post-mounted delineators, and other treatments have been conducted, but the results are difficult to generalize. The variation of conditions among practical installations, as well as the differences inherent in the various delineation treatments, makes prediction of visibility distances approximate at best. The wide range in driver vision capabilities, and the great importance of the driver "set," attention, or expectancy further complicate estimations in a practical setting.

Appendix J thus is a brief introduction to the variables in visibility and their relative importance. A general discussion of units and techniques for evaluating visibility, plus some definitions, criteria, and relationships, are presented in a simplified form. Illustrative data and useful formulas for calculations or conversions also are presented, with the emphasis on comparison of retro-reflective materials, specifically corner-curb reflectors and glass-beaded sheeting.

Although Appendix J is not comprehensive, nor does it provide ready tables of "visibility distances," it should serve to put the variables into perspective and form a basis for better understanding of the selection, application, and maintenance of reflective devices. Further references are included for operating personnel who wish to extend their understanding of the formal techniques and analyses used in evaluating visibility.

Colored Pavements—Physical Characteristics

Skid resistance and color visibility were investigated. (See Appendix L.) There is considerable evidence that the colored pavement material used in this study—a synthetic resinous binder, color pigment, and a special aggregate (fine and light-colored)—has structural characteristics as a surface treatment at least as good as that of most asphaltic concrete overlays. Hence, no further attention was directed to durability.

Skid resistance values for six sections of colored pavements and adjacent standard pavements (including asphaltic concrete and portland cement concrete) were determined one, three, and five months after installation. The skid resistance of the colored pavements was very high initially, but, in common with other pavements, an appreciable reduction was noted by the fifth month. However, it is believed that the skid resistance characteristics have stabilized and the values will remain higher than those for the adjacent standard pavements.

The widespread use of this same paving material, without the color pigments, for repaving bridge decks in Pennsylvania, after considerable research and documentation, lends further evidence to the acceptability of the material from the wear and skid resistance standpoints.

In the visibility testing, a quantitative measure of color contrast was established and used to determine the effect of six independent variables on this measure. The measure, called the "chromaticity vector," was defined as a function of standard chromaticity charts, which characterize colors by a combination of dominant wavelength and purity; and a series of tests were run to establish its reliability as a measure of a subject's ability to differentiate between colors.

The six independent variables used in the testing were:

1. Pavement color.
2. Type of lighting.
3. The effect of rain.
4. Reflectorizing bead size and type.
5. Angle of incidence to the source light.
6. Simulated wear and weather exposure.

The principal results were as follows:

1. The chromaticity vector can be used to define a measure of color contrast between two samples. There is a correlation between the chromaticity vector and the ability of subjects to differentiate colors.

2. The distance at which colors can be correctly differentiated can be changed up to 100 percent through the selection of color and lighting conditions.

3. The chromaticity vector approaches zero as a water film is formed on the pavement. This is caused by the reflected light containing the characteristics of the incident light and not the reflecting surface of the pavement.

4. The use of low-angle lighting, including headlights, causes a rapid deterioration of the chromaticity vector length. Colors are much more visible with overhead lighting.

5. The addition of color-coded beads to the surface of the pavement produces somewhat greater color contrast under automobile headlights. However, the maximum contrast is well below that obtainable with overhead lighting. The use of clear beads produces brightness, but not color contrast, under automobile headlighting conditions.

6. There is considerable fading with time: the color becomes virtually non-detectable at night, and loses much of its impact during daylight.

Validation of Intermediate Criteria on Rural Horizontal Curves

There is much discussion in the literature concerning the use of intermediate criteria (such as speed and placement) as measures of effectiveness. These criteria can be used instead of accident rates as measures of treatment effectiveness where it is not feasible to conduct before-and-after or parallel studies using accident data. However, no validation of these measures exists; i.e., in most cases a proven correlation of these measures with accident rates does not exist.

A statistical validation of the intermediate criteria/accident relationship on horizontal curves through the use of multiple regression techniques was undertaken. (See Appendix Q for details.)

A sample of nine horizontal curves was selected. These curves were located throughout the State of Pennsylvania and exhibited accident rates that varied from 5.0 to 78 accidents per million vehicle-miles. The accident statistics were derived from accident histories for the years 1966-1969. Radius of curvature varied from 143 ft to 763 ft; ADT varied from 2,370 to 5,270. All sites were two lane and located in rural areas.

Speed and lateral placement data were taken at the midpoint and at the estimated point of curvature for both directions at each curve. The data were taken for free-flowing (i.e., not influenced by other traffic at the time the measurements were made) passenger cars during fair weather under nighttime conditions. More than 12,000 speed and lateral placement observations were made.

The spot speeds were taken with radar speed meters; vehicle placement was taken with contact strips connected to electronic recorders. An attempt was made to obtain the speed of the same vehicles at both the PC and midpoint and the lateral placement of the same vehicles at both the PC and midpoint.

A multiple regression analysis was performed on the data, yielding the following results for the outside lane:

$$A = -21.87 + 23.56\ \text{PVR} + 0.027D \qquad (1)$$

$$R^2 = 0.79$$

in which

A = accidents per million vehicle-miles;

PVR = placement variance ratio

$= \dfrac{\text{Variance of placement at midpoint}}{\text{Variance of placement at PC}}$;

D = average deceleration rate

$= \dfrac{(\bar{S}_{PC} - \bar{S}_M)(\bar{S}_{PC})}{L}$;

$\bar{S}_{PC}$ = average speed at PC, in mph;

$\bar{S}_M$ = average speed at midpoint, in mph;

L = distance from PC to midpoint in miles; and

R^2 = coefficient of determination; percentage of variation of accident rate explained by variations in the independent variables.

A two-tailed t-test indicates that the coefficient of PVR is significant at the 1 percent level. The simple correlation coefficient of A and PVR is 0.829; this statistic for A and D is 0.451.

A regression analysis was also performed for the data taken on the inside lane, but yielded less significant results. This was expected because it can reasonably be assumed that a high proportion of the accidents involve vehicles negotiating the outside lane.

Although conclusive results cannot be drawn on such a small sample (nine curves), the statistical analysis does indicate a fairly strong correlation between accident rates and the variance of lateral placement. Thus, if delineation treatments can be shown to reduce the variance in lateral placement, accident rates probably will also be reduced.

Additional research with much larger samples is necessary before the exact functional relationships between accident rates and various intermediate criteria are known with confidence.

Accident Analyses

The records of accidents gathered by state and local police provide a large amount of information that should be useful in determining accident causations with the purpose of changing conditions that are related to high accident rates. However, there are severe limitations to use of this body of information for studying the relevance of specific conditions, such as delineation, to accident causation.

Accident records must fill a variety of needs. The limitations in time spent in investigation, in interpreting and categorizing the details, and in processing large numbers of reports limit the depth of detail for any one purpose. Estimates of causation may still be more accurate when based on accident records as compared with other, more subjective information. It is possible to make better use of the potential of accident records if each category provided is cited with approximately equal frequency. If the present high-frequency items were further subdivided, the information content of the records would approach their limit, providing much more useful information. Although the storage requirement would not be increased, code allocation and reporting procedures would require some improvement.

The first use of accident records as a means for estimating the importance of delineation is based on the Accident Priority Program of the Federal Highway Administration. Each of the 48 contiguous states and the District of Columbia submitted coded data on their 20 highest accident locations. The initial test of this body of data compared 10 regions of the United States for the type of high-accident locations reported. There were significant differences between regions, with the Central Atlantic States and New England (inland) reporting relatively few intersection locations as particularly hazardous, whereas these regions and the Northern Midwest region listed curve locations more often than expected.

Regions also differed when divided into snowy and non-snowy groups. The snowy areas reported more interchange ramp locations, whereas bridge and culvert locations were more often listed where snow was rare. Delineation-related hazards also appeared to be reported more often in snowy regions.

Mountainous and non-mountainous regions were compared next. A higher incidence of curve locations and a lower incidence of bridges and culverts were reported for mountainous regions, but there were no implications for delineation.

When regions were dichotomized on degree of urbanization there were differences, with ramps and intersection delineation more often identified as related to hazards in the urban areas. Geometrics were more strongly implicated at non-intersection locations.

A final comparison was made between the general locations of high-accident sites and four subgroups of hazards reported as contributing to the accident rate. Pavement marking and delineation were reported as deficient in intersections but were listed less than expected on curve locations, and slightly less than expected on ramps and other locations.

All comparisons from the high-accident locations across the United States were made with chi-square analyses comparing observed rates with expected or evenly distributed (average) rates. This test, of course, allows considerable room for variations in interpretation, and only the more obvious comparison items are described.

The second use of accident records employed a 5 percent sample of accident data from Pennsylvania for 1969. By attempting to reduce the sample to those accidents in which delineation was a "probable" or a "possible" factor in causation, a measure of the ultimate influence of delineation on casualties and property damage losses was obtained.

Of the 14,612 cases in the sample, 1,683 occurred in rural, non-turnpike locations at night or in the daytime while there was snow, rain, sleet, or fog. These were the general conditions judged to be more demanding on delineation. Each record that qualified at this level was examined to eliminate those involving rear-end collisions, backing, pedestrians, or unspecified types, because delineation could have little direct influence on these. The final contingency for selecting a subset of accidents that could be expected to involve delineation was the type of causation factor listed. Of the 94 factors listed, 25 failed to be cited in the sample, which had been reduced to 1,293 cases at this point. An additional 45 factors were considered sufficient to rule out delineation. This left 24, of which

6 were chosen where delineation was judged to be a "probable" causation factor, 18 as "possible" factors.

The costs of the "probable" accidents were used as the lower estimate of the potential for improvement based on better delineation. This came to 2.9 percent of the total killed and injured in Pennsylvania in 1969, or 1.1 percent of the accidents with property damage of approximately $4 million. The high cost of rural, nighttime accidents was expected, with 2.6 times the average casualty rate and approximately $1,265 property damage per accident.

An estimate of the upper boundary of cost where delineation might be effective was obtained from a combination of the "probable" and the "possible" accident groups. Of the totals, 11 percent of the casualties, 4.5 percent of the accidents, and $14 million property damage resulted, for a mean of $1,113 property loss per accident.

Pennsylvania statistics are fairly representative of the nation, with 4.3 percent of the nation's fatalities while having 6.2 percent of the licensed drivers traveling on 3 percent of the roads. The higher driver/road ratio is probably somewhat balanced by the lower average speeds on Pennsylvania's rural road system, so that this estimate is not seriously inaccurate for the nation as a whole. Interpolated to a national scale, this implies that improvements in delineation might reduce up to 6,200 fatalities and perhaps $780 million in property damage annually.

These estimates are necessarily crude with this level of record processing and sample size from one state, but they establish an order-of-magnitude figure that puts delineation into better perspective as part of the planning processes.

The data base for these studies, and further analyses, are presented in Appendix S.

GUIDELINES FOR DECISION MAKING

A methodology for arriving at solutions to delineation problems is presented in this section. The methodology is essentially the same as that in Figure 1, but specific checklists and worksheets are provided here. A schematic diagram, summarizing the interrelationships among the various informational inputs and Guideline Forms discussed in this section, is shown in Figure 2.

Due to the wide variety of situations, treatment properties, and indirect benefit considerations inherent in the selection of delineation systems, the methodology must rely on subjective judgments—hard data simply do not exist to formalize and quantify the complex interrelationships.

Considerable attention has been devoted to formulating the decision-making methodology in such a manner that it can be followed to arrive at solutions to problems ranging from statewide policy down to treatment of a specific site. It will be an aid in selecting one treatment from many (e.g., pavement markings, post delineators, raised pavement markers, colored pavements); selecting configurations of a specific treatment (e.g., post delineators: one side vs both sides, amber vs crystal, alternative spacings); and selection of treatment systems (e.g., use of pavement markings and post delineators vs raised pavement markers).

Problem Analysis

A careful analysis of the problem is the first step in the procedure. In terms of delineation problems/solutions, the problem statement becomes essentially a statement of the information needs. It is important that these needs be

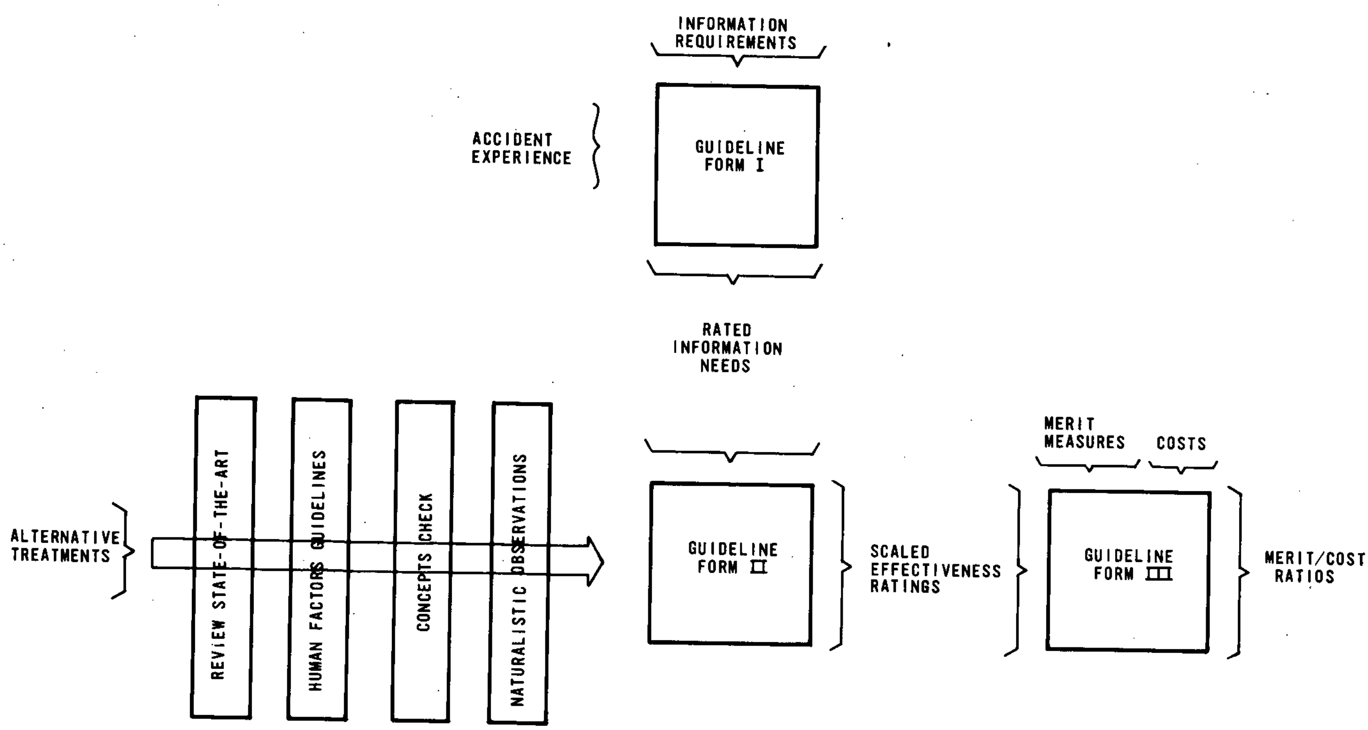

Figure 2. Use of guideline forms in decision-making.

carefully defined, as all other efforts in the total delineation treatments/systems selection methodology will be directed toward solving the problem as defined at this stage.

Guideline Form I (Fig. 3) has been developed to assist in the determination of information needs (related to delineation) from accident experience. The form shown in Figure 3 was developed specifically for the horizontal curve situation. Guideline forms for other previously identified "classical" situations are provided in Appendix R. A detailed explanation of the procedures for the development of these forms and derivation of the numerical values shown in Figure 3 are also included in Appendix R.

The basic approach consists of listing the accident experience (by type), judgment of the movements just prior to the accidents, and then assessment of the information deficiencies that led to the improper prior movements. This is a rational technique, relying heavily on expert judgment to relate prior movements to accidents, and information deficiencies to prior movements. Data for most of these relationships simply do not exist. However, use of this structured approach should provide improvement over the more conventional "seat-of-the-pants" approach.

The general methodology for this approach to achieving goals is provided in operations research literature. There is a slight twist, of course, because accidents are the *goals* for Guideline Form I and information deficiencies are the *means* for achieving the goals. However, information deficiencies can be converted to information needs, and satisfaction of these needs can be the goals for the remainder of the decision-making process.

The guideline forms developed, and included in this report, are primarily for the analysis of existing problems at specific situations. However, these forms can be used to determine information needs over a large number of sites by accumulating the accident experience (e.g., all horizontal curves over 5°, on a districtwide or statewide basis). If accident records are not available, a proportionate distribution can be estimated, on the basis of records from adjoining areas, literature search, etc. Obviously, as the dependability of the input information decreases, confidence in the assessment of the information needs must also decrease.

The guideline form as presented here is directed toward the delineation problem. Hence, accidents that clearly are not related to delineation should not be included in the listed accident experience. As considerable flexibility has been designed into the forms, it is possible to enter selected accident experience to determine special information needs (e.g., if only nighttime accidents are listed, then information needs pertinent to those accidents will be defined). Similar selectivity can be applied in the case of rain vs dry, fog vs no fog, etc.

Use of Guideline Form I

In Figure 4, the Horizontal Curve Situation Guideline Form (Fig. 3) has been completed to illustrate the procedures for using the form, and to provide an illustration of the output to be expected. The procedural steps are:

1. Listing of the accidents, by type (or estimated proportional distribution). The example shown here assumes nighttime accidents at a horizontal curve on a rural, two-lane highway.

2. The rating numbers in the upper left corners of the boxes below each of the "Information Requirements" (derivation shown in Appendix R) are multiplied by the number of accidents, by type, and the product is entered in the lower right portion of the box. For example, the rating under "Advanced Warning of Curves" for "Left Roadway" accidents is 41. (The 41 is a measure of the importance of deficiencies in "Advanced Warning of Curves" in "Left Roadway" accidents. The relative importance of the other information factors can be determined by examining the numbers in the upper left corners.) Hence, 164 ($= 4 \times 41$) is entered in the lower right cell.

3. The numbers in the lower right corners are then summed vertically to obtain a measure of the contribution of each of the information deficiencies to the accident experience at this specific site. Note that these numbers will add to 100 times the total number of accidents. The sums are then normalized by dividing by the number of accidents. The normalized sums provide a measure of the relative importance of the information deficiencies at this site that have contributed to the over-all accident experience.

This technique is simple to apply and structures a judgmental analysis of the information deficiencies that have contributed to accident experience. The answers, of course, are not absolutes—they are no better than the judgment exercised in developing the relative weights for the Information Requirements and the accuracy in selecting accident experience relevant to the problem under consideration. In this case, however, one can be fairly confident that the major sources of information deficiencies are "Advance Warning of Curves" and lack of definition of the "Degree of Curvature," and that treatments effective in providing these types of information should be given first priority in considering solutions to the accident problem at this site.

Treatment Effectiveness Evaluation

Once the information deficiencies (needs) have been determined the next step is to select alternative treatments or systems of treatments, and evaluate their effectiveness in supplying the deficient information. A second Guideline Form has been devised to provide a rational approach to this procedure, and its structure and use are discussed later in this section.

Before quantifying the effectiveness of the various treatments, however, a review of pertinent portions of this report should be made to familiarize the user with the specific properties of the various treatments, general delineation principles and concepts, and related experimental results. (See Fig. 2.)

Review the State of the Art

At this stage in the decision-making process, Appendices A, C, and D should be carefully reviewed. Appendix A reviews current practices and research related to the ap-

SITUATION:

HORIZONTAL CURVE

ACCIDENT TYPE			NO.	PRIOR MOVEMENTS									INFORMATION REQUIREMENTS							
				HIGH SPEED ENTRY	CENTER LINE ENCROACHMENT	SHOULDER ENCROACHMENT	PREMATURE ACCELERATION	RAPID DECELERATION	ADJACENT LANE ENCROACHMENT (MULTI-LANE)				ADVANCE WARNING OF CURVE	LOCATION OF BEGINNING OF CURVE	DIRECTION OF CURVE	DEGREE OF CURVATURE	LOCATION OF APEX	LATERAL POSITION LIMITS		
COLLISION WITH VEHICLE	ON-COMING	HEAD-ON											39	15	3	28	4	11		100
		SIDE-SWIPE											31	13	3	28	8	17		100
	SAME DIRECTION	REAR-END											39	15	2	33	3	8		100
		SIDE-SWIPE											19	14	3	28	6	30		100
LEFT ROADWAY													41	9	0	32	5	13		100
SUM																				
NORMALIZED SUM																				

Figure 3. Guideline Form I—horizontal curve.

SITUATION: HORIZONTAL CURVE				PRIOR MOVEMENTS									INFORMATION REQUIREMENTS							
ACCIDENT TYPE			NO.	HIGH SPEED ENTRY	CENTER LINE ENCROACHMENT	SHOULDER ENCROACHMENT	PREMATURE ACCELERATION	RAPID DECELERATION	ADJACENT LANE ENCROACHMENT (MULTI-LANE)				ADVANCE WARNING OF CURVE	LOCATION OF BEGINNING OF CURVE	DIRECTION OF CURVE	DEGREE OF CURVATURE	LOCATION OF APEX.	LATERAL POSITION LIMITS		
COLLISION WITH VEHICLE	ON-COMING	HEAD-ON	1										39 / 39	15 / 15	3 / 3	28 / 28	4 / 4	11 / 11		100 / 100
		SIDE-SWIPE	2										31 / 62	13 / 26	3 / 6	28 / 56	8 / 16	17 / 34		100 / 200
	SAME DIRECTION	REAR-END	1										39 / 39	15 / 15	2 / 2	33 / 33	3 / 3	8 / 8		100 / 100
		SIDE-SWIPE	0										19 / 0	14 / 0	3 / 0	28 / 0	6 / 0	30 / 0		100 / 0
LEFT ROADWAY			4										41 / 164	9 / 36	0 / 0	32 / 128	5 / 20	13 / 52		100 / 400
SUM			8										304	92	11	245	43	105		800
NORMALIZED SUM			1										38	12	1	31	5	13		100

Figure 4. Guideline Form I—horizontal curve; site analysis.

plication of various treatments to the geometric situations and summarizes literature pertinent to driver delineation needs. Appendix C provides information related to the physical aspects of delineation treatments, such as the materials used, maintenance problems, costs, environmental effects, and new or unique ideas. Appendix D summarizes delineation practices and experience in other countries.

A summary of the major points in all these appendices is included in the first part of this chapter.

Human Factors Guidelines

An important area of consideration is the drivers' capabilities in terms of vision and information processing. It is, however, unfortunately true that a translation from research results in these fields to definitive statements relevant to delineation treatment selection is not straightfoward. This is largely due to the high degree of interdependence of the many factors involved in "seeing" and the wide variability of conditions in which the driver is required to operate. For example, the attention-getting value of a particular object is mainly a function of the contrast between the object and the background against which it is viewed. For the driver, not only is the background constantly changing, but other factors that also influence his perception are operating in an unpredictable fashion (e.g., total available illumination, familiarity, colors involved, area of the retina stimulated).

It is obviously not practical to provide guidelines that include modifying statements covering all of the contingencies; they would be so long and complex as to be useless in practice. Hence, in the statements in Table 1, the factor judged to be the most powerful determinant is cited, and the most practical related delineation considerations are given.

Concepts Check

Even for a given specific situation (e.g., horizontal curve, lane drop), it is not possible to formulate universally applicable delineation systems because of the wide diversity of geometrics and environmental conditions. Hence, a number of basic concepts were postulated and tested through field and laboratory experiments. These concepts, listed in Table 2, should be reviewed for guidance in selecting candidate delineation systems. In particular, a check should be made to assure that none of the candidate systems violates the concepts, or, if it does, that this conflict is recognized in assessing the relative effectiveness of alternative treatments/systems.

Summaries of the studies related to these concepts are provided earlier in this chapter. Detailed descriptions of the laboratory and field studies are included in the appendices noted with each of the statements.

Naturalistic Observations

As in the case of the basic concepts, the results of the naturalistic observation studies should be reviewed in assessing the effectiveness of various delineation treatments/systems. A listing of these studies follows for a convenient reference; summaries of the results are included in an earlier section of this chapter, and the detailed descriptions are included in the noted appendices.

- Colored pavements—traffic operations (Appendix K).
- Colored pavements—physical characteristics (Appendix L).
- Post delineators and raised pavement markers on horizontal curves (Appendices M and N).
- Center line marking patterns (Appendix O).
- Stop approach treatments (Appendix P).

Use of Guideline Form II

An example of Guideline Form II, to be used in rating the relative effectiveness of various treatments in meeting the information deficiencies as derived from Guideline Form I, is shown in Figure 5. In order to provide continuity in illustration of the use of these forms, the horizontal curve situation is used again. The categories of "Information Requirements" for horizontal curves listed across the top of the form are consistent with those used in Guideline Form I. The candidate treatments are listed in the left column.

The step-by-step procedure for completing the form is described in the following paragraphs and illustrated in Figures 6 and 7:

1. Enter the weighted information deficiencies for each of the "Information Requirements," as determined from Guideline Form I.

2. List the candidate treatments (six are listed in Fig. 6). Note that some treatments are completely different from the others, whereas a few are merely variants (e.g., addition of edge lines). (As another example, if a decision had already been made to use post delineators at horizontal curves on rural two-lane highways, all the candidate systems might be variants; e.g., changes in spacing, color, left and/or right sides.)

Also, colored pavement has never been seriously advocated as a treatment for horizontal curves. It is included here for comparative purposes and to indicate that it would be a reasonably effective treatment, but will eventually be ruled out on cost considerations.

3. The numbers in the upper left corners of the divided cells in Figure 6 are then entered. These represent the relative effectiveness of each of the treatments in meeting the information requirement (deficiency) listed at the top of the column. Each column should be done independently, with a value of 10 being assigned to the treatment that best fulfills the information requirement; the other treatments are then rated relative to the "best" treatment. As indicated earlier, these evaluations should be made after careful review of the state-of-the-art appendices, the human factors guidelines, the concepts check, and the naturalistic observations studies.

4. The effectiveness ratings in Figure 6 are then "normalized" by proportionately increasing each rating until the sum for each column is 100. This assures that the total contribution of each information requirement to the

TABLE 1

HUMAN FACTORS GUIDELINES

NO.	STATEMENT	GUIDELINE
1.	NORMAL VISUAL ACUITY OF THE DRIVER IS SUCH THAT EVEN UNDER ADVERSE ROAD CONDITIONS HE CAN USUALLY SEE WELL ENOUGH TO DETECT AND UTILIZE THE INFORMATION FROM MOST CURRENTLY EMPLOYED DELINEATION TREATMENTS--	THEREFORE: SELECTION OF DELINEATION TREATMENTS NEED NOT BE CONSTRAINED BY ACUITY CONSIDERATIONS. (EXCEPT FOR LEGIBILITY OF RELATED SIGNS.)
2.	THE MORE IMPORTANT MONOCULAR CUES FOR DEPTH (AS RELATED TO DISTANCE JUDGEMENT) ARE SIZE AND FAMILIARITY--	THEREFORE: DELINEATION TREATMENTS SHOULD STANDARDIZE SIZE (e.g., POST DELINEATORS, MARKERS) AND SHOULD BE CONSISTENT IN APPLICATION.
3.	STEREOPTIC VISION IS NOT EFFECTIVE IN JUDGING DEPTH AT MORE THAN 500 FT. AND IS SEVERELY RESTRICTED UNDER CONDITIONS OF LOW ILLUMINATION--	THEREFORE: DELINEATION TREATMENTS SHOULD BE DESIGNED TO PROVIDE ASSISTANCE TO THE DRIVER IN THESE DIFFICULT DISTANCE JUDGMENTS (e.g., BEGINNING AND END OF PASSING ZONES, EXTENT OF PAVEMENT TAPER IN A LANE DROP).
4.	THE PROBABILITY OF SEEING ANY SINGLE GIVEN OBJECT IN A COMPLEX VISUAL ENVIRONMENT IS GREATLY REDUCED BY THE OPERATION OF SUCH FACTORS AS EYEBLINKING, RESTRICTIONS ON THE FIELD OF VIEW, THE RETINAL AREA STIMULATED, ETC.--	THEREFORE: THE USE OF CONTINUOUS (e.g., LINES) AND/OR REPETITIVE (e.g., POSTS) DELINEATION TREATMENTS IS CLEARLY INDICATED.
5.	PERIPHERAL VISION IS AN IMPORTANT SOURCE OF OF CUES REGARDING VEHICLE SPEED--	THEREFORE: THE USE OF POST DELINEATORS ON LONG TANGENTS WILL (AT NIGHT) ASSIST THE DRIVER IN HIS VISUAL ASSESSMENT OF HIS SPEED.
6.	COLOR CODES HAVE BEEN SHOWN TO BE VERY USEFUL IN TASKS WHICH REQUIRE RAPID LOCATING--	THEREFORE: THE USE OF COLOR CODES IN DELINEATION IS INDICATED IN CASES WHERE THE PATH OF SAFE TRAVEL MUST BE LOCATED AT HIGH SPEED--i.e., SHORT REACTION TIMES.
7.	COMPARISONS OF SHAPE AND COLOR CODES INDICATE THAT DIFFERENT COLORS ARE MORE RELIABLY DISCERNED THAN ARE DIFFERENT SHAPES--	THEREFORE: THE USE OF COLOR CODES IS TO BE PREFERRED OVER SIMPLE SHAPE CODES.
8.	BRIGHTNESS CONTRAST IS THE SINGLE MOST IMPORTANT FACTOR DETERMINING WHETHER OR NOT AN OBJECT IS SEEN--	THEREFORE: THE SELECTION OF DELINEATION TREATMENTS MUST INSURE MAXIMUM CONTRAST. AT NIGHT, SINCE MOST OF THE BACKGROUND IS DARK, THIS IS NO PROBLEM; BUT WHEN THE DELINEATION IS NEEDED IN DAYTIME, CARE MUST BE TAKEN TO PROVIDE APPROPRIATE CONTRAST.
9.	BRIGHTNESS AND BRIGHTNESS CONTRAST OF DELINEATION TREATMENTS VIEWED AT NIGHT IS PROVIDED MAINLY BY HEADLIGHT ILLUMINATION--	THEREFORE: THE PLACEMENT OF DELINEATION TREATMENTS MUST BE MODIFIED TO COMPENSATE FOR GEOMETRICS WHICH CAUSE THE BEAM TO BE DIRECTED AWAY FROM THE IMMEDIATE LINE OF TRAVEL-- (e.g., POST DELINEATORS ON THE <u>INSIDE</u> OF A 6° RIGHT CURVE RECEIVE ONLY 1/4 THE STRAIGHT ROAD ILLUMINATION).
10.	SENSITIVITY TO COLOR CHANGES AS THE LEVEL OF ILLUMINATION CHANGES--	THEREFORE: WHEN COLOR OF THE TREATMENT IS A CRITICAL INFORMATION COMPONENT, PROVISION MUST BE MADE TO INSURE TRANSMISSION OF THE PERCEPTION OF COLOR.
11.	PERIPHERAL VISION IS QUITE SENSITIVE TO MOVEMENT AND THIS IS GOOD FOR INITIAL DETECTION, BUT CENTRAL VISION IS REQUIRED FOR INTERPRETATION AND PERCEPTION OF DETAILS AND COLORS--	THEREFORE; DELINEATION TREATMENTS PLACED IN THE PERIPHERY MUST NOT BE DEPENDED UPON TO TRANSMIT PRECISE INFORMATION.
12.	THE ABILITY TO SEE AN OBJECT VARIES DEPENDING UPON THE PART OF THE RETINA STIMULATED, AND FOR THE DRIVER THE AREA STIMULATED IS DEPENDENT UPON THE PHYSICAL LOCATION OF THE OBJECT RELATIVE TO HIS LINE OF SIGHT--	THEREFORE: THE PLACEMENT OF CRITICAL DELINEATION SHOULD BE PLANNED TO COINCIDE WITH THE AREA OF BEST VISION TO ENHANCE PROBABILITY OF PROPER IDENTIFICATION.
13.	IT HAS BEEN SHOWN THAT FOR CONSCIOUS INFORMATION PROCESSING A HIGH RATE OF ACTIVITY ON ONE TASK EFFECTIVELY BLOCKS THE ACCOMPLISHMENT OF OTHER TASKS--	THEREFORE: IN AREAS OF HIGH TRAFFIC DENSITY WHERE A HIGH RATE OF PROCESSING REGARDING OTHER VEHICLES IS REQUIRED, PROCESSING OF DELINEATION INFORMATION WILL BE SUPPRESSED UNLESS IT HAS HIGH ATTENTION-GETTING VALUE.
14.	WHEN INFORMATION PROCESSING LOADS BECOME EXCESSIVE, REORGANIZING OR CODING OF INFORMATION HAS BEEN SHOWN TO BE HELPFUL--	THEREFORE: IN COMPLEX SITUATIONS (SUCH AS INTERSECTIONS, INTERCHANGES, ETC.) SIMPLE, WELL-UNDERSTOOD DELINEATION CODES SHOULD BE EMPLOYED TO REDUCE THE REQUIREMENT FOR PROCESSING INDIVIDUAL VISUAL INPUTS.
15.	INFORMATION HANDLING RATE IN TERMS OF ACCURACY HAS BEEN SHOWN TO BE A FUNCTION OF BOTH PRESENTATION RATE AND UNCERTAINTY--	THEREFORE: WHERE SPEEDS ARE HIGH THE NEED FOR CONSISTENCY OF DELINEATION TREATMENT IS GREATER SINCE STANDARDIZATION WILL FACILITATE LEARNING AND REDUCE UNCERTAINTY.
16.	INDIVIDUAL SIGNALS WHICH FOLLOW CLOSELY THE OCCURRENCE OF OTHER STIMULUS/RESPONSE EVENTS HAVE A HIGH PROBABILITY OF BEING MISSED--	THEREFORE: IN SITUATIONS SUCH AS RAMPS, INTERSECTIONS, LANE DROPS, ETC., WHERE THE DRIVER MUST ATTEND TO AND ACT UPON A LARGE NUMBER OF STIMULI, DELINEATION INFORMATION SHOULD BE PRESENTED IN A REPETITIVE OR CONTINUOUS FORM TO REDUCE THE POSSIBILITY THAT IT WILL BE MISSED.
17.	IN TRACKING TASKS, UP TO A 10% REDUCTION IN PROCESSING TIME HAS BEEN SHOWN TO RESULT WHEN ANTICIPATORY INFORMATION IS PROVIDED--	THEREFORE: THE USE OF DELINEATION TREATMENTS WHICH INHERENTLY PROVIDE ADVANCE WARNING OF CHANGING GEOMETRICS, OR THE PLACEMENT OF TREATMENTS SUCH THAT THIS WARNING IS PROVIDED, IS DESIRABLE.
18.	RESPONSE UNCERTAINTY DETRIMENTALLY AFFECTS PERFORMANCE, BUT ITS EFFECT IS LESSENED UNDER CONDITIONS OF STIMULUS/RESPONSE COMPATIBILITY--	THEREFORE: DELINEATION TREATMENTS SHOULD BE CONFIGURED SO AS TO SUGGEST THE APPROPRIATE RESPONSE (e.g., PAVEMENT TURN ARROWS ARE PREFERRED TO THE VERBAL MESSAGE ''TURN LEFT'').
19.	INFORMATION WHICH IS SOMETIMES RELEVANT, SOMETIMES IRRELEVANT, HAS BEEN SHOWN TO BE DETRIMENTAL TO OVERALL TASK PERFORMANCE--	THEREFORE: DELINEATION TREATMENTS SUCH AS CHANNELIZING PAINT SHOULD BE APPLIED ONLY WHEN NECESSARY AND THEN IN A FASHION WHICH ENCOURAGES THE DRIVER TO CONFORM.
20.	REDUNDANT INFORMATION, WHILE HELPFUL IN MANY CASES, CARRIES THE INHERENT DANGER OF BECOMING, IN CERTAIN UNCLUTTERED SITUATIONS, IRRELEVANT INFORMATION WHICH IS DETERIMENTAL TO PERFORMANCE--	THEREFORE: IN VISUALLY ''CLUTTERED'' SITUATIONS, REDUNDANCY (i.e., REPETITIVE) DELINEATION TREATMENTS COULD BE EXPECTED TO HAVE A FACILITATIVE EFFECT BY PROJECTING A STRONG MESSAGE THROUGH THE CLUTTER, WHILE IN LESS COMPLEX SITUATIONS THE SAME TREATMENTS MAY PRODUCE CLUTTER.

over-all effectiveness rating will be in direct proportion to its weight. The normalized ratings are then entered in the upper left corners of the corresponding cells in Figure 7.

5. The values in the upper left corners in Figure 7 are then multiplied by the weighted information deficiency value at the top of the respective column. These expanded values are entered in the lower right corners.

6. The values in the lower right corners are added horizontally to obtain the "Total Effectiveness Rating" for each candidate system; e.g., 889 for "painted center line."

7. All ratings are then divided by the highest one, and then multiplied by 10, to scale the ratings to a base of 10 for entry into Guideline Form III (discussed in the next section).

The effectiveness ratings can be taken as an indication of the relative success of each of the treatments in meeting the over-all information requirements.

As in the case of Guideline Form I, the technique is simple to apply and provides a structure for a comprehensive judgmental analysis. Again, the primary limitation is that the scaled effectiveness ratings can be no better than the judgment exercised in developing the relative ratings for the effectiveness of each treatment in meeting each information requirement.

The scaled effectiveness ratings apply to treatments as used at the specific horizontal curve for which the accident data were entered into Guideline Form I. A shift in that accident experience would create a shift in the weighted information deficiencies; these changes would change the values indicated in the lower right corners of Figure 7; and, consequently, a change in the over-all scaled effectiveness ratings for the various candidate treatments. Fortunately, the accident experience/information requirements/treatment effectiveness relationships are relatively

TABLE 2

DELINEATION CONCEPTS

NO.	CONCEPT	GUIDELINES
1.	POSITIVE VS. NEGATIVE DELINEATION	POSITIVE TREATMENTS AND SYSTEMS THAT INDICATE THE CORRECT TRAVEL PATH ARE PREFERRED TO NEGATIVE TREATMENTS THAT INDICATE WHERE NOT TO DRIVE. (APPENDIX I)
2.	CLUTTER	MIXING DELINEATION TREATMENTS MAY PRODUCE CLUTTER WHICH MASKS EFFECTIVENESS OF INDIVIDUAL TREATMENTS, i.e., TOTAL SYSTEM MAY BE LESS EFFECTIVE THAN A SINGLE COMPONENT; MIXTURES OF POSITIVE AND NEGATIVE TREATMENTS MOST COMMON. (APPENDIX G)
3.	TWO-LINE VS. SINGLE-LINE SYSTEMS	VARIOUS EXPERIMENTS INDICATE TWO-LINE SYSTEMS TO BE SUPERIOR TO SINGLE-LINE SYSTEMS; EXAMPLE, STRONG DRIVER PERFERENCE FOR EDGE LINE AND CENTER LINE (PERCEIVED AS A PLANE) OVER CENTER LINE ALONE (SINGLE LINE). (APPENDIX G & &)
4.	OVERDELINEATION	MAY INDUCE UNDESIRABLY HIGHER SPEEDS UNDER ADVERSE VISIBILITY CONDITIONS; NO EFFECT ON MEASURED PERFORMANCE UNDER GOOD VISIBILITY CONDITIONS, BUT MAY BE DRIVER IRRITANT AND NON-COST-EFFECTIVE; QUANTUM CHANGES REQUIRED TO BE NOTICEABLE TO DRIVERS. (APPENDIX F & J)
5.	TARGET VALUE OR DETECTION EFFECTIVENESS	CERTAIN COLORS, SHAPES, PATTERNS OR CODES ARE ''STRONGER'' THAN OTHERS. (APPENDIX H)
6.	CODING	SEVERAL ASPECTS INVESTIGATED (APPENDIX G) INTRINSIC CODES STRONGLY PREFERRED; e.g., ARROW-SHAPED OR BENT-ROD POST DELINEATORS IMMEDIATELY RECOGNIZABLE WITH NO TRAINING, WHEREAS MOST DRIVERS DO NOT RECOGNIZE THE USE OF DOUBLE AMBER POST DELINEATORS ON EXIT RAMPS AS A CODE. COLOR, PER SE, RELATIVELY WEAK INTRINSIC CODE; e.g., USE OF RED POST DELINEATORS ON APPROACH TO STOP SIGNS RELATIVELY INEFFECTIVE. COLOR CHANGES VERY EFFECTIVE CODING TECHNIQUE, i.e., CHANGE IN COLOR WILL DRAW ATTENTION, BUT MEANING OF CHANGE MUST BE PROVIDED BY CODE OTHER THAN INTRINSIC VALUE OF COLOR ITSELF. SHAPE CODING HIGHLY EFFECTIVE, BUT PROBLEMS WITH MANUFACTURE, INSTALLATION, MAINTENANCE, AND COSTS.
7.	ADVANCE AND NEAR DELINEATION	ADVANCE DELINEATION PROVIDES ANTICIPATORY INFORMATION AND BENEFITS ARE MEASURED IN DRIVER COMFORT AND EASING REQUIREMENT FOR CONTINUAL ATTENTION TO TRACKING TASK; NEAR DELINEATION USED FOR LATERAL CONTROL AND PROVIDES STRONGEST SPEED CUES; DRIVER PERFORMANCE, AS MEASURED BY INTERMEDIATE CRITERIA (SPEED, LATERAL PLACEMENT, ETC.), NOT SENSITIVE TO ADVANCE DELINEATION (BEYOND APPROXIMATELY 150 FEET), BUT NEAR DELINEATION TREATMENTS DO AFFECT THESE MEASURES.
8.	SPACING CODES	QUANTUM CHANGES REQUIRED BEFORE DRIVERS NOTICE DIFFERENCE; USED EFFECTIVELY IN ENGLAND WHERE GAPS ARE SEVERELY SHORTENED AND LINE SEGMENTS CONSIDERABLY LENGTHENED IN CENTER LINE PATTERN ON APPROACH TO HAZARDOUS AREAS.

SITUATION: HORIZONTAL CURVE	INFORMATION REQUIREMENTS							TOTAL EFFECTIVENESS RATING	SCALED EFFECTIVENESS RATING
	ADVANCE WARNING OF CURVE	LOCATION OF BEGINNING OF CURVE	DIRECTION OF CURVE	DEGREE OF CURVATURE	LOCATION OF APEX	LATERAL POSITION LIMITS			
TREATMENT	WEIGHTED INFORMATION DEFICIENCIES								

Figure 5. Guideline Form II—horizontal curve.

SITUATION: HORIZONTAL CURVE	INFORMATION REQUIREMENTS							TOTAL EFFECTIVENESS RATING	SCALED EFFECTIVENESS RATING
	ADVANCE WARNING OF CURVE	LOCATION OF BEGINNING OF CURVE	DIRECTION OF CURVE	DEGREE OF CURVATURE	LOCATION OF APEX	LATERAL POSITION LIMITS			
TREATMENT	WEIGHTED INFORMATION DEFICIENCIES								
	38	12	1	31	5	13			
PAINTED CENTER LINE ONLY	3	3	3	4	7	4			
PAINTED CENTER LINE AND EDGE LINES	3	5	3	7	9	8			
RAISED PAVEMENT MARKERS CENTER LINE ONLY	8	9	9	8	9	6			
RPM CENTER LINE AND PAINTED EDGE LINES	8	10	10	10	10	10			
PAINTED CENTER LINE AND POST DELINEATORS; OUTSIDE CURVE	10	7	7	8	8	4			
COLORED PAVEMENT WITH PAINTED CENTER LINE	4	8	8	6	9	5			

Figure 6. Guideline Form II—horizontal curve; treatment effectiveness ratings.

SITUATION: HORIZONTAL CURVE	INFORMATION REQUIREMENTS							TOTAL EFFECTIVENESS RATING	SCALED EFFECTIVENESS RATING
	ADVANCE WARNING OF CURVE	LOCATION OF BEGINNING OF CURVE	DIRECTION OF CURVE	DEGREE OF CURVATURE	LOCATION OF APEX	LATERAL POSITION LIMITS			
TREATMENT	WEIGHTED INFORMATION DEFICIENCIES								
	38	12	1	31	5	13			
PAINTED CENTER LINE ONLY	8 / 304	7 / 84	9 / 9	9 / 279	14 / 70	11 / 143		889	3.8
PAINTED CENTER LINE AND EDGE LINES	8 / 304	12 / 144	9 / 9	16 / 496	17 / 85	21 / 273		1311	5.7
RAISED PAVEMENT MARKERS CENTER LINE ONLY	22 / 836	21 / 252	25 / 25	19 / 589	17 / 85	16 / 208		1995	8.6
RPM CENTER LINE AND PAINTED EDGE LINES	22 / 836	24 / 288	28 / 28	23 / 713	19 / 95	27 / 351		2311	10.0
PAINTED CENTER LINE AND POST DELINEATORS; OUTSIDE CURVE	29 / 1102	17 / 204	20 / 20	19 / 589	15 / 80	11 / 143		2138	9.3
COLORED PAVEMENT WITH PAINTED CENTER LINE	11 / 418	19 / 228	9 / 9	14 / 434	17 / 85	14 / 182		1356	5.9
	100	100	100	100	100	100			

Figure 7. Guideline Form II—horizontal curve; scaled effectiveness ratings.

insensitive, and the ratings for most sites will be similar. Hence, the ratings have widespread applicability and need not be recomputed for moderate changes in accident experience input.

Construction of these guideline forms is straightforward for each situation for which a Guideline Form I is shown in Appendix R. Therefore, they are not illustrated here.

Treatment/System Selection

If the overwhelming consideration and impetus for the specific study being made is to reduce a bad accident experience, it may be that the investigation can be considered complete once Guideline Form II has been filled out. This is particularly true if the costs are in a relatively narrow range and all the alternatives are budget-feasible. This situation may arise frequently when considering delineation treatment for a specific site. On the other hand, if the alternatives vary greatly in cost, or if a policy-type decision is being made that will require widespread implementation, use of Guideline Form III (see Fig. 8) to structure a consideration of variables other than costs and to assess the overall-all merit/cost relationship is suggested. This latter approach is similar to the utility/cost approach described by Kay (*381*). (It may be helpful to reexamine Figure 2 at this point.)

Merit Measures

There are several measures that can be applied to assess the merit of a delineation treatment/system besides its effectiveness as an accident-reduction agent. The following are suggested as the most pertinent to the majority of delineation situations—Guideline Form III is flexible enough that other measures can be used if the individual study requires them:

1. *Normalized treatment effectiveness rating*—These values are derived directly from Guideline Form II and have already been scaled such that the most effective treatment has a rating of 10, and the others have been rated in relation to the "best" treatment.

2. *Applicability over varying conditions*—The treatment effectiveness ratings were developed in consideration of a specific accident experience, and consequently were derived to be effective under specific conditions of weather, traffic volume, ambient lighting, etc. This factor permits an evaluation of the generalizeability of the treatment across other combinations of weather, volume, etc. If the major thrust of the investigation is to "solve" the accident problem at a specific site, this factor should receive a relatively smaller weight; on the other hand, if a policy statement is being generated that must apply across diverse situations, this factor will receive relatively more weight.

3. *Indirect benefits*—Driver comfort, public acceptance, and general aesthetic considerations comprise this factor. These can be powerful determinants. For example, strong driver preference for edge lines will probably dictate their use for the foreseeable future, even though only limited data exist to indicate that they are effective as an accident-reduction measure. (It is likely that the public would demand edge lines even if studies indicated an adverse effect.) It seems likely, also, that adverse criticism of "unsightly" delineation treatments will become a more important factor as the public's concern for environmental quality and aesthetics grows.

4. *Freedom from maintenance*—Note that "maintenance" must be changed to a positive aspect for entrance in Guideline Form III; i.e., the system with the *least* maintenance problems has the most merit, and must receive the 10 rating. If the maintenance costs can be definitively stated (such as scheduled periodic repainting of center lines), they can be considered a part of the treatment/system cost, discussed later. Other aspects of maintenance, such as traffic interruption (which increases with shorter cycle lengths) and nuisance to mowing operations, are included in this factor. Another consideration, linked to the applicability criterion, is the relationship of the degradation of the treatment with varying maintenance cycles.

5. *Ease of implementation*—The ease with which the installation and maintenance of candidate treatments can be accomplished is also an important factor. If the maintenance requirements are such that they must be scheduled at the same time that other critical operations must be carried out, the system is obviously less desirable than one that will provide work during slack periods. Also, a treatment requiring new and unique equipment or manpower, particularly at the expense of existing equipment and manpower, will also be undesirable.

6. *Consistency with local delineation practices*—In some cases, a treatment may be inconsistent with local delineation practices. This may be good, if a "startle" effect is desired; but it may create problems in interpretation for drivers, as well as problems in the factors mentioned just previously. In general, it will not be desirable to delineate one site in a manner radically different from the treatments used at other sites with the same general geometric characteristics (e.g., use of post delineators on the outsides of some curves and not on others along the same stretch of roadway may result in an adverse effect on the undelineated curves).

Each of these six factors must be given a relative weight, totaling to 100. These weightings will obviously vary greatly with the nature of the problem, especially when considering treatment for a specific site as opposed to a statewide policy procedure. Also, the pertinent subfactors within each category will vary from treatment to treatment, by geometric situation, and with the agencies making the investigation.

Assessment of Delineation Costs

The intent within this section is to supply guideline cost figures for the various delineation treatments. It is expected, however, that individual agencies will use their internal data where possible. It is believed that the figures provided here will be of most value when considering state- or regionwide programs where considerations of large investments over diverse conditions are required. Much

SITUATION: HORIZONTAL CURVE	MERIT MEASURES									
	TREATMENT EFFECTIVENESS RATINGS	APPLICABILITY OVER, VARYING CONDITIONS	INDIRECT BENEFITS	FREEDOM FROM MAINTENANCE	EASE OF IMPLEMENTATION	CONSISTENCY WITH LOCAL DELINEATION PRACTICES		MERIT RATING	COST	MERIT/COST RATIO
TREATMENT	WEIGHTS (MERIT MEASURES)									

Figure 8. Guideline Form III—horizontal curve.

"tighter" estimates will be possible for each agency for installations at specific sites.

The costs are presented in two fashions. First, the costs of the various delineation materials are listed without reference to the situation at which they may be applied. Second, the costs of three delineation treatments (standard pavement markings, post delineators, and raised pavement markers) at a given horizontal curve are noted for comparison.

The cost figures were compiled from various sources, including documented cost studies, state surveys, conversations with state highway officials, manufacturers' price lists, and project staff estimates. Although every effort was made to obtain realistic cost values, they should not be considered precise actual costs to be used in a final decision before implementing a delineation treatment. Because material costs vary widely throughout the U.S. and also with method of application, both a low and a high cost are presented, as well as an average cost. Wherever feasible, the costs are presented on a common basis for ease of comparison.

Costs for five delineation materials are summarized in Table 3. The cost categories are the unit cost for the material, the initial installation cost (including labor and equipment), and the total cost incurred for a five-year period. In most cases, the costs are shown on a per foot basis. For post delineators and raised pavement markers a reasonable spacing was assumed in order to convert the unit price into a per foot price. Inasmuch as rumble strips and colored pavement are both area applications, costs for these categories are quoted on a square yard basis.

1. *Pavement markings*—The cost figures given in Table 3 are based on a nationwide survey conducted by Chaiken in 1969 (*44*). In this survey, he found the average cost for a continuous 4-in. line to be $0.022 per foot. However, reported costs ranged from a low of $0.009 to a high of $0.05 per foot. The wide range of costs is probably due to different accounting practices, materials used, and painting operations. The service life can vary considerably and is greatly influenced by the climate. States experiencing heavy snow usually cannot expect more than 6 months of service life, whereas those without snowfall indicate that paint can sometimes last more than a year. Two five-year costs are shown for paint markings to account for one and two paint cycles per year.

The figures for thermoplastic markings are also taken from Chaiken's survey. The life of thermoplastic paint is greater when applied on bituminous surfaces than on concrete surfaces, and is also greater for non-snow states. Thermoplastics have not been used extensively on rural roads because of their higher costs.

2. *Post delineators*—The installed cost for post-mounted retro-reflective delineators ranges from a low of $3.00 to a high of $5.15 each. The range is attributed to the different types of posts and reflectors available. The service life of a post delineator is not easily determined; it is not a linear function of time and traffic wear as in the case of paint. Damages usually arise from snowplowing operations, shoulder encroachment of vehicles, and vandalism. States with heavy snow have experienced a 50 percent or more replacement factor each year. The figures for five years are based on a replacement factor of 20 percent and a spacing of 200 ft, which is normal for tangent sections.

3. *Raised pavement markers*—A wide variety of raised pavement markers is available; unit costs range from a low of $0.25 each for non-reflective markers to $1.25 or more for reflective markers. Snowplowable markers cost as much as $3.00 to $5.00 each. The life of the markers for non-snow states appears to be between 3 and 5 years, with a loss replacement factor of about 10 percent per year. Table 3 gives prices for a solid line pattern and a broken line pattern. These prices are based on patterns that simulate paint lines; the cost would be lower if the markers were employed as a supplement to paint markings.

4. *Rumble strips*—Rumble strips are applied in several ways, as described in Appendix C. Commonly, this treatment consists of stone chips bound by some type of adhesive mixture, or simply a ½-in. layer of bituminous concrete. The average cost for this type of application is about $2.00 per square yard. A service life of five years can be expected in most cases, with little or no maintenance. Hence, the total cost for five years is the same as the initial installation cost. Another type of rumble strip is scored concrete (see Appendix C for more detail). Although it has been placed transversely across the pavement, it is generally used for median sections running longitudinally. This application has an average cost of about $4.00 per foot for a 4-ft-wide stripe. Again, little maintenance is required during a long service life (sweeping or some other type of cleaning will be required where sand or cinders are used for anti-skid control on icy pavements or other loose material is present on the roadway).

5. *Colored pavement*—The various methods of obtaining colored pavement are described in Appendix C. The costs given in Table 3 are for the synthetic resin mix. Because colored pavement is still rather unusual, the costs tend to be high. The total cost, including labor, materials, and equipment, incurred by the Pennsylvania Department of Transportation for installing the colored pavement studied in this project was $3.50 per square yard; the materials costs alone amounted to $3.00 per square yard. Although the colored pavement material will suffice as a surface layer for up to 8 years, the service life of the "color" might be considerably less.

As a further comparison of the costs of delineation, an example is given in Table 4 showing the costs for delineating a two-lane horizontal curve. The curvature is assumed to be 20°, with length of curve equal to 440 ft. The total delineation treatment length is 1,040 ft, which allows 300 ft of tangent lead-in for both ends of the curve.

A total five-year cost for delineating both lanes is presented. Reflected in this price is the total installation cost and maintenance for five years. Both low and high values are given, which usually reflect differences in snow versus non-snow states. Colored pavement and rumble strips are not itemized because these are not normally applied to curve sections.

TABLE 3

COSTS AND SERVICE LIVES OF DELINEATION MATERIALS

MATERIAL		UNIT COST	TOTAL INSTALLATION COST[a]			SERVICE LIFE	TOTAL 5-YEAR PROJECT COST[b]		
			LOW	HIGH	AVG		LOW	HIGH	AVG
1. PAVEMENT MARKINGS	a. REFLECTORIZED PAINT (4'' CONT. LINE)	\$2.00/GAL (.7¢/FT	\$0.009/FT	\$0.05/FT	\$0.022/FT	3-12 MO.	\$0.04/FT[c] 0.08/FT[d]	\$0.22/FT 0.44/FT	\$0.10/FT 0.19/FT
	b. THERMOPLASTIC (4'' CONT. LINE)	0.50/LB	0.25/FT	0.49/FT	0.33/FT	1-5 YRS[e] 2-8 YRS[f]	0.46/FT[e] 0.25/FT[f]	0.90/FT 0.49/FT	0.61/FT 0.33/FT
2. POST DELINEATORS (ONE 3'' REFLECTOR ON POLE)		0.30 EA. (REFLECTOR ONLY)	3.00 EA.	5.15 EA.	4.00 EA.	5 YRS[g]	0.028/FT[h]	0.04/FT[h]	0.033/FT[h]
3. RAISED PAVEMENT MARKERS	a. NON-REFLECTIVE	.25-.50 EA.	---	---	---	---	---	---	---
	b. LOW-INTENSITY	.60-1.00 EA.	0.19/FT[i]	0.25/FT[j]	0.22/FT	3-5 YRS	0.24/FT[i]	0.29/FT[j]	0.26/FT
	c. HIGH-INTENSITY	.80-1.25 EA.	---	---	0.13/FT[k]	---	---	---	0.17/FT[k]
	d. SNOW-PLOWABLE REFLECTIVE	3.00-5.00 EA.	4.00 EA.	7.00 EA.	5.50 EA.	---	---	---	---
4. RUMBLE STRIPS	a. RAISED BITUMINOUS OR STONE SURFACE	---	1.50/YD^2	2.50/YD^2	2.00/YD^2	3-8 YRS	1.50/YD^2	2.50/YD^2	2.00/YD^2
	b. SCORED CONCRETE (4 FT. WIDE)	---	---	---	4.00/FT	5-10 YRS	---	---	4.00/FT
5. COLORED PAVEMENT (SYNTHETIC RESIN MIX; 1/2-3/4'' LAYER)		---	1.30/YD^2	3.50/YD^2	2.40/YD^2	5/8 YRS	1.30/YD^2	3.50/YD^2	2.40/YD^2

a. COST INCLUDES MATERIALS, EQUIPMENT, LABOR
b. TOTAL COST INCLUDING ANNUAL MAINTENANCE AND DISCOUNTED @ 6%.
c. ASSUMES 1 PAINT CYCLE PER YEAR
d. ASSUMES 2 PAINT CYCLE PER YEAR
e. FOR CONCRETE SURFACE.
f. FOR BITUMINOUS SURFACE.
g. A REPLACEMENT FACTOR AS HIGH AS 50% PER YEAR CAN BE EXPECTED IN SNOW STATES.
h. ASSUMES A SPACING OF 200 FEET.
i. COST FOR SOLID LINE PATTERN--NON-REFLECTIVE MARKERS ON 4-FT CENTERS AND HIGH INTENSITY REFLECTIVE MARKER EVERY 24 FT., SINGLE LINE.
j. COST FOR SOLID LINE PATTERN--LOW INTENSITY MARKERS ON 4-FT CENTERS, SINGLE LINE.
k. AN AVERAGE COST FOR SKIP LINE PATTERN-- 4 NON-REFLECTIVE MARKERS, ON 3-FT CENTERS, EVERY 24 FT AND 1 REFLECTIVE MARKER EVERY 48 FT (CALIFORNIA PATTERN).

TABLE 4

COSTS OF DELINEATION FOR HORIZONTAL CURVE ON TWO-LANE RURAL ROAD ($D_C=20°$; Length of treatment=1,040 ft.)

TREATMENT		TOTAL 5 YR. PROJECTED COST	
		LOW	HIGH
1. PAVEMENT MARKINGS	a. STANDARD PAINT LINES (DOUBLE CENTER LINE AND EDGE LINES)	$416	$790
	b. THERMOPLASTIC PAINT	$1373	$2538
2. POST DELINEATORS		$ 242	$ 332
3. RAISED PAVEMENT MARKERS	a. RPMs FOR DOUBLE CENTER LINE W/PAINTED EDGE LINES	$ 449 $ 657	$ 603 $ 998
	b. RPMs SUPPLEMENTAL TO PAINTED CENTER LINE W/PAINTED EDGE LINES	$ 125 $ 541	$ 125 $ 915

PAVEMENT MARKINGS.-- THE STANDARD PAINT STRIPING FOR A CURVE USUALLY CONSISTS OF A DOUBLE YELLOW CENTER LINE AND WHITE EDGE LINES; ALL 4 INCHES WIDE . A LOW FIVE-YEAR COST OF $416 AND A HIGH FIVE YEAR COST OF $790 IS SHOWN. THE LOWER FIGURE ASSUMES ONLY ONE PAINT CYCLE PER YEAR WHILE THE HIGHER VALUE ASSUMES TWO PAINT CYCLES. BOTH PRICES ARE BASED ON A 2.2 CENTS PER FOOTAGE COST FOR A 4-INCH WIDE CONTINUOUS LINE.

PRICES ARE ALSO SHOWN FOR THERMOPLASTIC PAINT. AS EXPECTED, THE COSTS FOR THERMOPLASTIC ARE CONSIDERABLY HIGHER. THERMOPLASTIC PAINT REQUIRES A LONG LIFE TO BE ECONOMICALLY COMPETITIVE WITH STANDARD PAINT. THE LOW VALUE OF $1373 ASSUMES THAT THE THERMOPLASTIC DOES NOT HAVE TO BE REPLACED WITHIN 5 YEARS, WHEREAS THE HIGH VALUE OF $2538 ASSUMES ONE REPLACEMENT. REPLACEMENT OF THERMOPLASTIC IS DEPENDENT UPON SURFACE (BITUMINOUS VS. CONCRETE), PRESENCE OF SNOW, AND VOLUME OF TRAFFIC.

POST DELINEATORS,-- FOR A $D_C=20°$, A POST DELINEATOR SPACING OF APPROXIMATELY 30 FEET IS REQUIRED, WITH A TRANSITIONAL SPACING OF 54, 90 AND 180 FT. A TOTAL OF 21 DELINEATORS IS REQUIRED FOR THE TREATED SECTION FOR EACH DIRECTION (ONLY THE OUTSIDE OF THE CURVE IS TREATED). THE LOW VALUE OF $242 ASSUMES AN INSTALLED COST OF $3.00 EACH, WHILE THE HIGH VALUE OF $332 ASSUMES AN INSTALLED COST OF $5.15. BOTH FIVE-YEAR COSTS ARE BASED ON A 20% REPLACEMENT FACTOR PER YEAR FOR BOTH THE REFLECTOR AND POST.

RAISED PAVEMENT MARKERS.-- BECAUSE OF THE DIFFERENT TYPES OF MARKERS AVAILABLE, THERE IS NO STANDARD SPACING PATTERN FOR HORIZONTAL CURVES. RAISED PAVEMENT MARKERS CAN BE USED ALONE TO SIMULATE STANDARD PAVEMENT MARKINGS OR THEY CAN BE USED TO SUPPLEMENT PAINT LINES. PRICES ARE QUOTED FOR BOTH OF THESE SITUATIONS.

WHERE RPMs ARE USED ALONE TO SIMULATE A DOUBLE YELLOW CENTERLINE THE COSTS RANGE FROM A LOW OF $449 TO A HIGH OF $603. THE LOW VALUE IS BASED ON A PATTERN WITH NON-REFLECTIVE MARKERS ON 4-FT CENTERS AND HIGH INTENSITY REFLECTIVE MARKERS EVERY 24 FEET; THE HIGH VALUE IS BASED ON A PATTERN OF LOW INTENSITY MARKERS ON 4 FOOT CENTERS. WHILE EDGE LINES COULD BE SIMULATED OR SUPPLEMENT BY RAISED PAVEMENT MARKERS, THIS PRACTICE IS NOT IN CURRENT USE. INSTEAD, THE COSTS FOR STANDARD PAINTED EDGE LINES ARE SHOWN.

WHEN RPMs ARE USED AS A SUPPLEMENT TO THE PAINTED CENTER LINE, THE COSTS ARE APPRECIABLY REDUCED. THE PRICE OF $125 IS BASED ON A HIGH INTENSITY MARKER EVERY 24 FEET. THE HIGH AND LOW VALUE IS DIFFERENT DUE TO THE VARYING PAINTING CYCLES.

To obtain the values in Table 4, the total five-year cost given in Table 3 was multiplied by the length of the treated section and modified for necessary changes in pattern. A more detailed description is provided in the footnotes.

Use of Guideline Form III

Guideline Form III is designed to permit integration of the effectiveness of the various treatments, as determined from Guideline Form II, with other policy considerations to develop a comprehensive merit rating for each of the treatments. The costs of each of the treatments are then tabulated and a merit/cost ratio is obtained. The horizontal curve situation is used again to illustrate the compatibility of the three guideline forms for a single project.

The step-by-step procedure for completing Guideline Form III is as follows:

1. Enter the merit measures as the appropriate column headings. Six measures are suggested in this example, but they could be varied to suit the individual situation and agency. (See Fig. 9.)

SITUATION HORIZONTAL CURVE	TREATMENT EFFECTIVENESS RATINGS	APPLICABILITY OVER VARYING CONDITIONS	INDIRECT BENEFITS	FREEDOM FROM MAINTENANCE	EASE OF IMPLEMENTATION	CONSISTENCY WITH LOCAL DELINEATION PRACTICES		MERIT RATING	COST	MERIT/COST RATIO
	MERIT MEASURES									
TREATMENT	WEIGHTS (MERIT MEASURES)									
	40	15	20	10	10	5				
PAINTED CENTER LINE ONLY	3.8	3	2	8	10	10				
PAINTED CENTER LINE AND EDGE LINES	5.7	4	5	8	10	8				
RAISED PAVEMENT MARKERS CENTER LINE ONLY	8.6	8	8	10	8	8				
RPM CENTER LINE AND PAINTED EDGE LINES	10.0	9	10	7	7	7				
PAINTED CENTER LINE AND POST DELINEATORS; OUTSIDE CURVE	9.3	10	7	6	8	9				
COLORED PAVEMENT WITH PAINTED CENTER LINE	5.9	3	3	8	3	5				

Figure 9. Guideline Form III—horizontal curve; merit ratings.

2. Enter the weights for each of the merit measures. The weights given in the example are not proposed as universally applicable—considerable variation is possible, but the final decision must lie with the individual user and policy-maker.

3. List the candidate treatments from Guideline Form II. Also, transfer the scaled effectiveness ratings from Form II to the upper left corners of the cells in the appropriate column.

4. Each of the treatments must be rated against each of the merit measures listed. This should be done column by column, assigning a value of 10 to the best treatment, and then rating the others relative to that one. These values are entered in the upper left corners of the cells, as in Figure 9.

5. As in the case of Guideline Form II, the ratings must be proportionately increased so as to sum to 100. These adjusted ratings are entered in the corresponding cells in Figure 10.

6. The values in the upper left corners of Figure 10 are then multiplied by the weights at the top of the respective columns. These products are entered in the lower right corners.

7. The numbers in the lower right corners are added horizontally to obtain the total merit rating for each candidate treatment.

8. The cost for each candidate treatment is then entered in the following column. If a specific site is being studied, the cost for the total treatment application at that site can be determined through use of an analysis similar to that in Table 4, or from local records and experience. If the treatments are more general, and widespread implementation will be the ultimate result, a unit basis must be used (e.g., cost per mile, or per horizontal curve).

9. The merit rating is then divided by the cost to determine the merit/cost ratio.

Figure 10 indicates that the treatments utilizing raised pavement markers or post delineators have the highest merit ratings; those depending on painted lines for nighttime visibility are noticeably weaker. (Colored pavement is not really applicable for this situation, and its inclusion was primarily to show that it would be "washed out" in the final analysis.) Comparison of the first two pairs of treatments (i.e., the second and fourth treatments, consisting of the addition of edge lines to the first and third, respectively) indicates that edge lines do strengthen the treatments. However, when cost is considered, and merit/cost ratios are computed, the edge line treatments exhibit lower ratios. This is not entirely surprising, as the primary emphasis in this example was on accident reduction, whereas the installation of edge lines is generally based on popularity with the driving public as well as on effectiveness as an accident-reduction measure. [A few studies have indicated a reduction in certain types of accidents (*2, 6, 10, 36, 100*).]

Over all, then, it is concluded, on the basis of the accident experience at this hypothetical location and the indicated weights for the merit measures, that raised pavement markers should be installed as a center line treatment. However, the addition of edge lines will strengthen this treatment, and if edge lines are used on other portions of the road, obviously they are being justified on some basis and should be continued through this curve.

If it is assumed that the accident experience used as input to Guideline Form I is representative of the accidents throughout the state, the merit/cost ratios have more significant meanings, as the costs become more meaningful when widespread application is considered. Again, raised pavement markers on the center line provide the most merit per dollar of investment. However, if the budget is limited, it may be more desirable to provide painted center lines over more curves as the merit/cost ratio is nearly the same and the investment per site is much less. On the other hand, if painted center lines are already provided and replacement by raised pavement markers is not feasible (perhaps snowplows operate in some parts of the state), the addition of post delineators to the outsides of the curves will provide a very strong treatment with a high merit/cost ratio.

SUMMARY COMMENTS ON DECISION-MAKING GUIDELINES

A methodology for selecting delineation treatments, with specific checklists and guideline forms, has been presented. The following points, relative to this methodology, deserve emphasis:

1. The methodology must rely heavily on subjective judgments due to the wide variety of situations, treatment properties, and merit measures that will be encountered in the application of the procedures.

2. The methodology can be applied to a wide range of delineation problems, from treatments at a specific site through the development of policy decisions for statewide implementations.

3. Careful definition of the problem is essential, inasmuch as the methodology is designed to solve the stated problem. Because the major consideration in this project was accident reduction, the problems are formulated in those terms. However, a representative proportional listing of accidents by type can be used as the input for more general problems. Historical accident experience, of course, will be used where a specific site is being investigated.

4. It is necessary to keep the problem clearly in mind throughout the completion of the guideline forms—the ratings will be dependent on this information. (Hence, even though one of the advantages of this methodology is that it is possible to derive a consensus judgment by averaging the results from several experts, it is important that they clearly understand the character of the accident experience input.)

5. As indicated in Item 4, the methodology can be used to derive a consensus of experts from various related disciplines. (A few methods for aggregating these opinions are discussed in Appendix E.)

6. The answers are not absolutes; they are no better than the judgment exercised in developing the relative weights for the various factors used throughout the guideline forms. In any case, the methodology will be effective in

SITUATION: HORIZONTAL CURVE / TREATMENT	MERIT MEASURES: TREATMENT EFFECTIVENESS RATINGS	APPLICABILITY OVER VARYING CONDITIONS	INDIRECT BENEFITS	FREEDOM FROM MAINTENANCE	EASE OF IMPLEMENTATION	CONSISTENCY WITH LOCAL DELINEATION PRACTICES		MERIT RATING	COST	MERIT/COST RATIO
WEIGHTS (MERIT MEASURES)	40	15	20	10	10	5				
PAINTED CENTER LINE ONLY	9 / 360	8 / 120	6 / 120	17 / 170	22 / 220	21 / 105		1095	302	3.6
PAINTED CENTER LINE AND EDGE LINES	13 / 520	11 / 165	14 / 280	17 / 170	22 / 220	17 / 85		1440	603	2.4
RAISED PAVEMENT MARKERS CENTER LINE ONLY	20 / 800	22 / 330	23 / 460	21 / 210	17 / 170	17 / 85		2055	526	3.9
RPM CENTER LINE AND PAINTED EDGE LINES	23 / 920	24 / 360	28 / 560	15 / 150	15 / 150	15 / 75		2215	827	2.7
PAINTED CENTER LINE AND POST DELINEATORS; OUTSIDE CURVE	21 / 840	27 / 405	20 / 400	13 / 130	17 / 170	19 / 95		2040	589	3.5
COLORED PAVEMENT WITH PAINTED CENTER LINE	14 / 560	8 / 120	9 / 180	17 / 170	7 / 70	11 / 55		1155	4750	0.2

Figure 10. Guideline Form III—horizontal curve; merit/cost ratios.

narrowing down the field of possible candidates (i.e., the results should indicate which two or three alternatives hold the most promise).

7. Familiarity with the material in the section entitled "Treatment Effectiveness Evaluation" is essential to effective use of the guideline forms.

8. Selection and weighting of the merit measures must be done by the individual user, as these are inherently closely related to agency policies.

9. The cost data must be consistent, either as a total cost for the total treatment application, or some meaningful unit cost.

10. Because the cost/merit relationship is assessed in the final stages of the decision analysis, more sophisticated methods of cost-effectiveness evaluation may be employed as they become available, without disturbing the major portion of the analysis structure.

11. This methodology, then, provides a structure for a rational analysis of a complex problem involving monetary and non-monetary considerations. Implementation, and subsequent in-field determination of actual merit (e.g., accident reductions), of course, must be employed as a final proof.

CHAPTER THREE

INTERPRETATION AND APPRAISAL

DUAL APPROACH TO STUDY OF DELINEATION PROBLEMS

Two basic approaches to the study of delineation problems were taken in this project. The first, followed primarily by those with training in psychology, was directed at determining root causes of erratic driver behavior, which in turn might result in involvement in accidents. These studies were conducted primarily in the laboratory or under controlled field conditions where data regarding individual subject behavior, decision, estimates, or opinions could be obtained. The end results of these studies were basic concepts, primarily related to detection, identification, and information processing, that can be applied across various situations. The specific treatments employed were a secondary consideration.

The other approach, followed primarily by the engineers on the project team, was to look for obvious inadequacies in delineation practices and then attempt to remedy them. Most of the studies in this area involved application of specific treatments to specific situations, and observation of normal traffic in a naturalistic setting. Measures of effectiveness included comparative rates of erratic maneuvers, changes in mean speeds and lateral placements or variances of these quantities, and judgmental opinions of the researchers and, on some occasions, state traffic engineering personnel. In general, data collection periods were long (contrasted to those in the laboratory or field settings), and variations in group driver behavior were of interest, with little emphasis on the individual drivers. Conclusions regarding the applicability of specific treatments for specific problems were drawn, with generalization to other situations being made through judgmental extrapolation.

These two approaches were integrated in the formulation of a decision-making methodology, including the development of the guideline forms in Chapter Two.

DELINEATION SITUATIONS

For organizational purposes, the study and much of this report are structured around a set of geometric situations. This is particularly apparent in Appendix A, where driver information needs and delineation requirements are considered. As pointed out there, although the number of potential geometric situations encountered in the field is large, these can be collapsed into a relatively small number of highly similar situations in terms of information-decision-action patterns. These patterns, or models, become the basis for determining information requirements in the driving task that might be furnished by delineation treatments or systems. Such models are essential in selecting systems, or evaluating them, in order to assure that all desirable information is furnished and extraneous information is not provided. Ideally, the driver will have just the information he needs and no other to add to his information processing load.

Highway and traffic engineers will most often use the report results in situation-specific terms—i.e., they will turn to the report when they have a specific curve, intersection, merging area, etc., or particular section of road to delineate. The need for delineation of a specific site may arise from new construction or recognition as a hazardous area. Policy decisions, on the other hand, may be made either by situation (e.g., a new delineation policy for horizontal curves) or by treatment (e.g., an edge lining policy that applies across several situations). In either case the user of this report can easily match his needs to a "classical" case and determine the information requirements, review the pertinent research and current practices, and make use of the appropriate guideline forms.

APPRAISAL OF SAFETY EVALUATION

Throughout this project, accident reduction has been considered to be the primary role of delineation. The study concentrated on delineation of rural two-lane roads. It is believed that maximum accident-reduction benefits from improved roadway delineation systems will occur on such roads.

Obviously, other considerations are important in formulating delineation policies. Proof of this can be seen in the widespread use of edge lines, a relatively expensive treatment for the roadway involved, with only limited statistical support for their value as an accident-reduction measure and no reported cost-effectiveness evaluations. This is not to suggest that edge lines should not be provided, as they are extremely popular with the driving public, but rather to indicate that accident reduction is not the sole decision factor.

The guideline forms are organized such that use of the first two forms will permit evaluation of the safety aspects of delineation systems. The third form can be added, or not, depending on the desirability of integrating non-safety factors in the treatment selection process for the specific problem under study.

From a total project overview standpoint, perhaps the single most important observation or conclusion is that any type of basic delineation treatment and/or system will provide the major safety benefits to be derived from this class of highway-driver communication. This leads to the conclusion that the standard treatments are not ineffective; in fact, it can be observed that lack of consistent implementation of the standard practices called for in the state and national manuals is probably the source of most delineation-related accidents.

The intermediate measures of effectiveness used in the field studies were primarily erratic maneuvers, and means and variances of vehicle speeds or placements. It was observed that "far" delineation treatments (i.e., those treatments visible in the area beyond approximately 150 ft from the driver) did not affect the intermediate measures, even in tests of treatment vs non-treatment. For "near" delineation, statistically significant differences in the measures were frequently obtained, but the differences among the alternative treatments were generally much smaller than between almost any given treatment and no treatment—essentially, effectiveness was a matter of absence or presence of treatment. This is not to say that individual treatments (e.g., raised pavement markers, post delineators, pavement markings) do not have spheres of influence in which they are most appropriate, but that alternative spacings, colors, patterns, etc., within these treatment classes are of relatively little significance as compared to treatment versus non-treatment.

There are few data relating the application of specific treatments to reductions in accident rates; there are virtually none relating variations of treatments to changes in accident experience. One of the studies within this project was directed toward this problem (see Appendix Q). In this study, it was found that there is a strong correlation between the accident rate at a horizontal curve and the ratio of the variance of the lateral placements on the approach to the curve to the variance of the lateral placements within the curve. This is encouraging and may lead to a truly effective measure for the evaluation of delineation treatments at horizontal curves. Although it was established that existing accident rates are related to existing lateral placement measures, time did not permit determining if changes in treatments that would effect changes in the lateral placement properties would result in reduced accident experience at the specific sites being studied.

A much wider range of ratings for alternative treatments were obtained when subjective opinions were used as the evaluation measure. This is, perhaps, not surprising in that subjective evaluations certainly involve non-safety aspects of the delineation treatments—i.e., some treatment alternatives, involving changes in spacing, intensity, color, etc., were strongly preferred on a subjective basis; yet the effectiveness of these same treatments, as measured by the intermediate measures (and more particularly by accident experience) did not exhibit statistically significant differences.

In summary, it appears that major safety benefits will be derived from the provision of good treatments, but it is likely that variants of the treatments must be judged on factors other than accident reduction, such as cost, driver comfort, aesthetics, and maintenance consideration. The interpretation is that drivers compensate, at least in terms of measurable external actions, for the differences in the alternative delineation treatments.

The foregoing discussion can be used in support of or against the need for uniformity in delineation treatments. In one sense, because variants in the treatments do not appear to materially affect their safety effectiveness, there is no reason to permit variations. On the other hand, because there are strong preferences in the subjective area, particularly among engineers faced with widely varying environmental conditions (snowplowing, fog, etc.) and fiscal constraints, there appears to be no good reason to deny them their preference, as drivers easily compensate for the differences and accident rates can be expected to be little affected by the variations. Further, because the delineation treatments generally serve as aids to guidance and have some degree of continuity throughout the geometric situation to which they are applied, the decisions that are required on the basis of this information are not as discrete as for information obtained from signs. Therefore, uniformity is not as necessary as in the case of signs. (Regulatory delineation may be an exception—in particular, no-passing zone marking and legal interpretation should be standardized among the states.)

POTENTIAL BENEFITS FROM THE PROJECT

Accident Reduction

If the material developed within this study is used by practicing engineers, and in particular if the guideline forms are used to make delineation decisions, there is little doubt that accident reduction can be effected. However, it is not likely that vast improvements will be noted—and, again, the major safety benefits will be derived from the consistent and widespread application of good treatments, rather than from variations in the spacing, intensity, etc., of the treatments themselves.

Further, the accident types that are amenable to reduction from improved delineation are those that result from driver actions in the "tails" of the normal distribution of driver behavior. That is, improvement will come from narrowing the variance of such driver actions as speed, lateral placement, and attention to the task, and the reduction of drivers who fall outside the "safe" zone for these actions. It is not likely that reductions can be accomplished in the "discrete" cases, caused by drunken driving, falling asleep, and deliberate overdriving.

Catalog of Delineation Information

This report provides a comprehensive catalog of findings relevant to the roadway delineation problem, including a definitive state-of-the-art summary, review of the pertinent human factors aspects, results from directly related field studies, and basic concepts drawn from the integration of this information. The bibliography lists a number of other reports from which more detail in specific areas can be obtained.

Definition of Information Needs

The information needs for drivers at various geometric situations are outlined and discussed in Appendix A. These can be used as the basis for evaluating the effectiveness of alternative treatments (appropriate effectiveness measures are indicated in the information models), and the information needs are directly related to required driver decisions, resulting in desired driver actions. Review of these models will provide the practicing engineer with the informational aspects of delineation at these situations.

Methodology for Delineation Decision Making

A methodology for delineation decision making, on a specific project or a statewide basis, has been developed. This methodology, described in detail in Chapter Two, provides a structure for effective judgmental decisions. On the basis of this study, it appears that no rigid formula or totally objective numerical effectiveness ratings can be supplied to the decision maker.

The information deficiencies for a given situation and the effectiveness of various alternative treatments in providing the deficient information can be assessed through the use of Guideline Forms I and II. Guideline Form III, supplemented with information from various parts of this report, enables the traffic engineer to select treatments on the basis of several criteria, including safety. More detailed discussion of evaluative techniques, including cost-effectiveness criteria, are provided in Appendices E and T.

In summary, the developed methodology will serve to strengthen the judgmental inputs to the decision-making process, and to elicit the most reasonable judgments from users.

Application Recommendations

The work on all aspects of this project has permitted formulation of comparatively specific recommendations for delineation practices across the various geometric situations, as presented in Chapter Four. As mentioned previously, these cannot be absolutes, due to the wide variety of environmental conditions, local policies regarding the treatments, the relative weights to be given to non-safety aspects, and individual agency fiancial constraints.

The implementation of these recommendations, the use of the guideline forms, and familiarity with the information developed in this project will lead to improved delineation practices and, therefore, improve highway safety and ease the driving task.

CHAPTER FOUR

APPLICATIONS

The most applicable product, in a general sense, is the set of guideline forms described in Chapter Two. Accompanying applicable products is the information in the various sections of the report, which, when absorbed by the user, strengthens the judgmental inputs to the forms.

Variations in climatic conditions, roadside development, ambient lighting, traffic volumes and compositions, agency policies and fiscal constraints, etc., make it impossible to formulate "universal truths" where specific treatments and/or systems are concerned. However, generally applicable recommendations regarding delineation treatments and systems for "classical" situations are provided in this chapter. These have evolved as consensus opinions of the research project staff and are based on extensive study of pertinent literature; discussions with other researchers and practicing highway engineers; participation in a delineation task force meeting for one state; analysis of the results of the office, laboratory, and field studies conducted within the project; and careful observation of current standard (and unique) delineation practices. Hence, some of the conclusions reached and recommendations made are supported by data; some are based on careful review of other researchers' work; some are the results of extrapolation of limited experimental data, with attention to conformance with basic human factors concepts; and still others were arrived at through joint synthesis of subjective information by the project team.

The qualifications regarding these recommendations are not repeated at each statement in the following discussion; the reader must decide if his particular circumstances dictate acceptance.

The recommendations are presented by situation, with the exception that comments relevant to several situations (e.g., regarding edge lines) are included in the first section, "Tangent and General Situations."

TANGENT AND GENERAL SITUATIONS

Pavement Markings

1. The gap-to-mark ratio for center lines should be increased from the present standards. This would result in a saving in paint material costs. England has used a 3-ft mark with a 24-ft gap for several years. (See Fig. 11.) This pattern was derived through laboratory simulation tests to study visual acceptance by drivers. It was also ascertained that the flicker rate for this pattern was satisfactory.

A study in the current project, using a 5-ft mark with a 35-ft gap (retaining the basic 40-ft module), with and without edge lines, indicated no meaningful changes in vehicle speeds or lateral placements. (See Fig. 12.)

From a human factors standpoint, the number of mark ends observed is of relatively more significance than the length of the marks; i.e., the shorter marks are almost as strong, because the number of ends per unit length of roadway is the same as for the standard patterns. In fact, the English pattern, with its shorter module, provides more ends with approximately the same amount of paint as used in the experimental study (approximately one-third the paint in the standard pattern).

Because this change would be substantial and have far-reaching consequences, it is suggested that further research be conducted in this area. Present indications are that Pennsylvania will conduct a more extensive program in the near future, with longer stretches of test road. The adoption of a weaker broken-line pattern in areas where it serves only to mark the center line of the road will permit the use of stronger broken lines in areas where special caution may be required but crossing the line is still permitted. (See Fig. 13.) This concept has been used extensively and successfully in England and some other European countries. A 4-in. line, with 20-ft mark to 10-ft gap, is suggested for the United States.

2. Continuous edge lines should be placed on all roads more than 22 ft in width, where traffic volumes justify the expenditure. It is particularly important where shoulders are bad. Long-term research studies indicate that a reduction in accident experience will be achieved with the installation of edge lines, but the studies are far from conclusive. In this matter, however, there seems little doubt that the public will demand the edge lines, and the expenditures should be made even if comparable savings from accident reduction cannot be assured.

3. The present 4-in. width should be retained for center lines and edge lines in the general case. Various widths of lines were installed in a study in England. It was concluded that the 2-in. line was unacceptable from an appearance standpoint, as the minor irregularities in alignment showed up clearly and the lines appeared wavy. On the other hand, 6-in. lines just provided "more of the same" when compared to the 4-in. lines, and the additional paint costs did not seem justified.

Eight-inch lines, solid and broken, could be used for special applications where crossing is permitted, but the driver should be aware that he is entering a non-standard zone; e.g., climbing lanes (see Fig. 14), and approaches to lane-drop exit ramps. A pattern of 10-ft mark, 10-ft gap is recommended.

4. For the wide two-lane roads encountered in the West, the 4-ft median being tested in Texas seems to have considerable merit. (See Fig. 15.) No research in this area was conducted within this project.

5. Under present-day relative cost conditions, the use of thermoplastic paints is restricted to special situations. They can be used in high-wear areas, particularly where periodic absence due to wear cannot be tolerated. Most of these situations occur in urban areas, rather than on rural highways. The strongest arguments for thermoplastics are that they are available for a larger percentage of the time than painted lines, and that traffic need not be interrupted as frequently as with paint lines.

6. As pointed out in the concept studies, drivers prefer a two-line to a single-line delineation system. This, in part, explains the strong preference for edge lines. Hence, no matter what treatment is used as a center line, it will be desirable to use a second line—either an edge line or a line of post delineators.

Post Delineators

1. Post delineators should be installed along the right side of two-lane rural roads. A spacing of 400 ft is adequate, as they serve simply as indicators that the roadway alignment is straight immediately ahead. A further stipulation is that three delineators should be visible at all times; this may necessitate somewhat closer spacing on winding, hilly roads.

2. Crystal or white delineators should be used on tangent sections.

3. The standard retro-reflective delineators, usually amber, should be removed from culvert markers, etc. ("negative" delineation) when the crystal delineators are used for "positive" delineation. The tops of the posts should be painted with reflectorized paint. This will make the posts visible to maintenance crews, but because of their low intensity they will not detract from the positive delineation pattern for the average driver.

Figure 11. Broken center line pattern, England (3-ft mark, 24-ft gap).

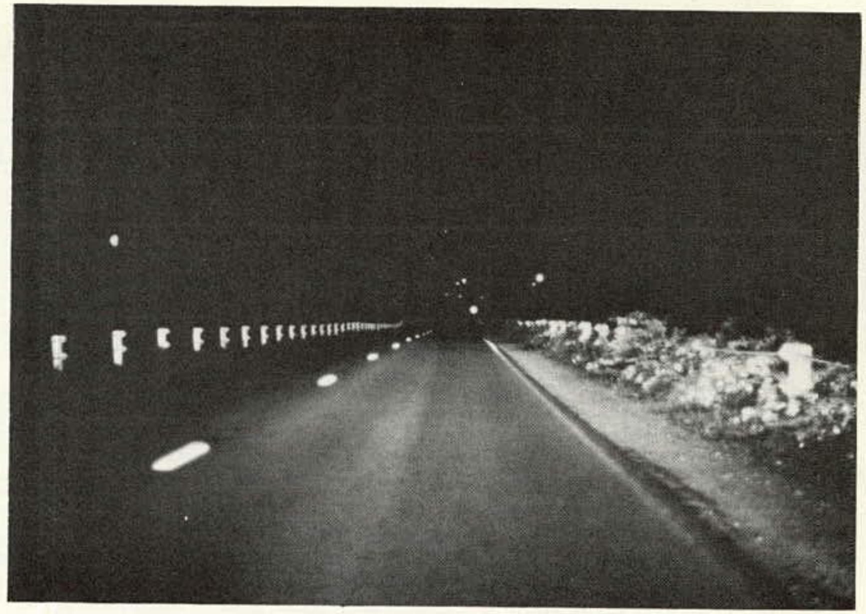

Figure 12. Test broken center line pattern (5-ft mark, 35-ft gap).

Figure 13. Change in strength of broken center line pattern, England.

Figure 14. Use of 8-in. broken line for climbing lane situation.

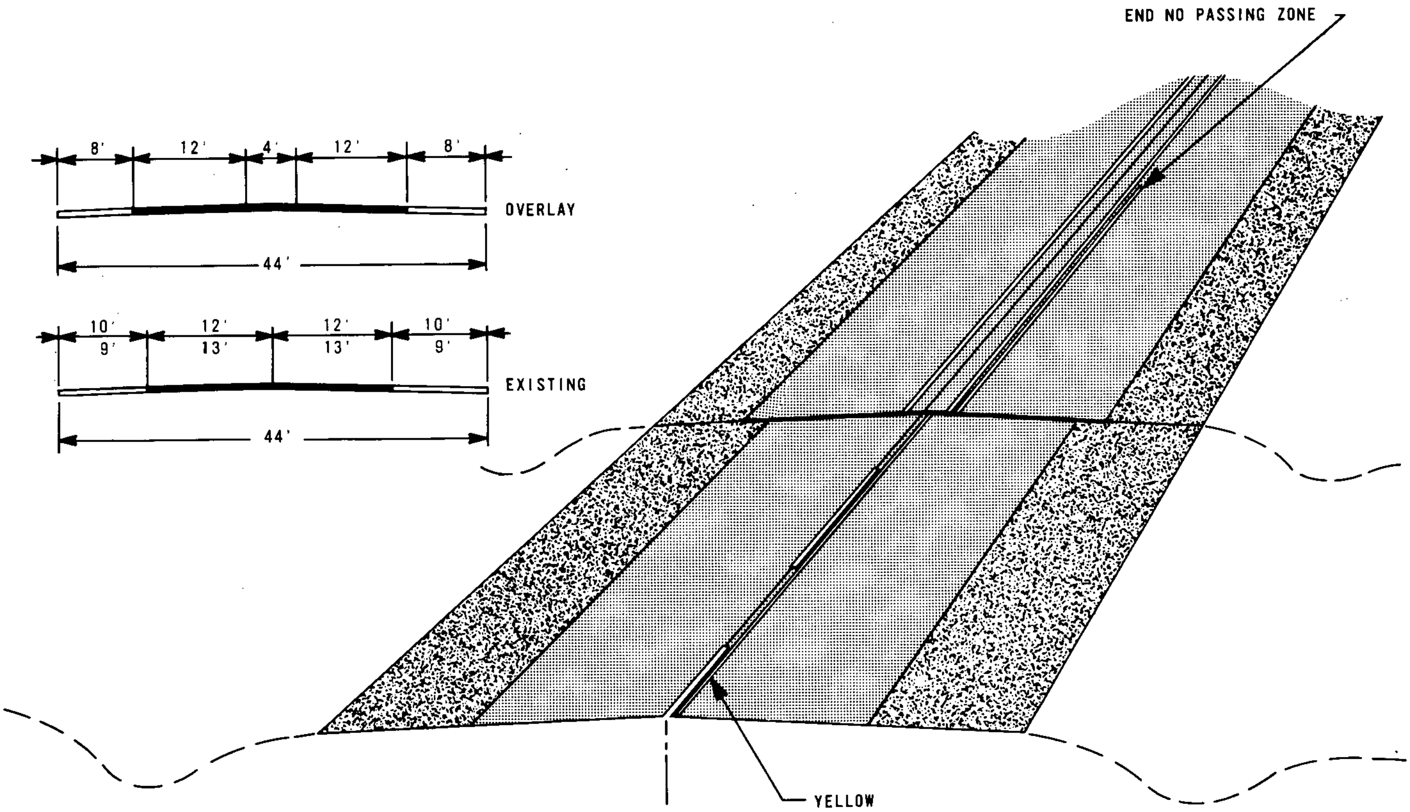

Figure 15. Pavement marking technique for wide two-lane roadways, Texas.

4. The "negative" delineators should not be removed when the positive delineation pattern is not employed. Even though not standard in application, they do give the driver some indication of the roadway alignment ahead.

5. Guardrails on tangent sections need not be marked in a special manner if the general positive delineation pattern is in force (additional markers at the ends of the guardrails will not be distracting if they are in line with the others and are crystal in color). Again, if the general positive delineation is not being used, marking of the guardrails is a good idea.

6. The "paddles" used in some states for daytime delineation are of limited usefulness, and should not be installed. In daylight these serve little purpose, as there are enough other natural cues to inform the driver of the roadway alignment. In addition, they are aesthetically unattractive—without them the post delineators are nearly invisible during the day (as they should be). (See Fig. 16.)

7. Emphasis should be shifted to the use of post delineators on rural roads, instead of on high-type facilities. Sudden changes of alignment and uncertainty of the roadway path are more prevalent on the two-lane roads.

Raised Pavement Markers

1. Standard pavement paint lines should be simulated (pattern and color) when raised pavement markers are used for daytime conditions. Ceramic markers are the most effective during the day. A spacing of 3 or 4 ft will simulate a solid line (or the solid part of a broken line). (See Fig. 17.)

2. It is not necessary to simulate broken lines with raised pavement markers at night; solid lines should appear solid at night, as well as during the day, however. For lane lines and other broken lines, a spacing of 80 ft is sufficient; this can be reduced to 40 ft in "warning" areas where crossing is permitted, but discouraged.

High-intensity markers (e.g., Stimsonite 88) spaced at 24 ft will give the appearance of a solid line at night (see Fig. 18); a spacing of about 6 ft is required if low-intensity markers are used. The first type derives its strength from brightness; the latter types, from density.

3. An acceptable pattern of raised pavement markers for right edge lines has not been reported in the literature, and the project's experiments did not include consideration of the markers for right edge lines.

4. The principal advantage of raised pavement markers is that they provide both near and far delineation, limited somewhat by the vertical profile of the road. As compared with painted lines for near delineation, the principal advantage is the increased visibility, particularly on rainy nights. In areas where snowplows operate, the standard types are destroyed. Snowplowable markers are available. (See Figs. C-11 and C-12.) To date, the purchase and installation costs are relatively high, and service lives are not adequately documented. Development is continuing.

As "far" delineation, the principal advantage of raised pavement markers over post delineators is the correspon-

Figure 16. Paddles for daytime delineation (use is discouraged).

dence of the line of raised pavement markers to the road surface. The principal advantage of post delineators is that they are visible over longer distances, particularly at crest vertical alignments.

HORIZONTAL CURVES

Pavement Markings

1. No changes in the standard markings at horizontal curves are suggested, except that if a more open broken-line pattern is adopted, a warning line (increased mark-to-gap ratio) could be used at gentle curevs and on approaches to the no-passing areas on curves.

2. If pavement width is sufficient, the addition of edge lines (on roads where they do not exist on the tangents) will improve lateral placement characteristics, with possible reduction in accident experience.

3. Pavement markings are good near delineation devices, but supplemental treatments with longer visibility distances are required to supply anticipatory information.

4. A two-line system is desirable for near delineation on horizontal curves. This could consist of two pavement lines (center line and edge line) or a combination of pavement markings and some other treatment.

Post Delineators

1. The most effective pattern, from the visual standpoint, is the use of post delineators on the outside of curves only. (See Fig. 19 and Figs. A-6 and A-7.) Amber delineators are recommended for right curves (left side of roadway) and crystal for left curves (right side of roadway). When post delineators are used on both sides, the pathway will be much clearer if the two-color system is used. It is possible many drivers would learn the color code with time, and recognition of the direction of the curve will increase their anticipatory information. Continued use of amber delineators at culverts, etc., on both sides of the roadway weakens this code considerably.

2. A post delineator spacing of $3\sqrt{R - 50}$ on curves is adequate.

3. Maintaining maximum delineator brightness is not really critical in terms of provision of direct accident-reducing information—the necessary driver actions can easily be taken after delineation is visible, if nominal brightness is still available. However, increasing anticipatory information will ease the driving task, and benefits will result from this factor. (No attempts were made to quantify these benefits in this project.) This should not be construed to imply that cleaning is unimportant, as heavy dirt films can reduce the brightness below an acceptable value.

4. Consistent application is desirable. Post delineators should be used at all curves over 5° of curvature having a central angle exceeding 20°.

Raised Pavement Markers

1. No change is necessary from the patterns of raised pavement markers used on tangent sections, other than the use of solid lines in no-passing areas of curves. Again, a stronger line (derived through closer spacing) than on the tangent could be used at gentle curves and approaches to solid-line sections.

2. Raised pavement markers can be an effective supplemental treatment on curves on two-lane roads where the

Figure 17. Simulation of solid line with raised pavement markers.

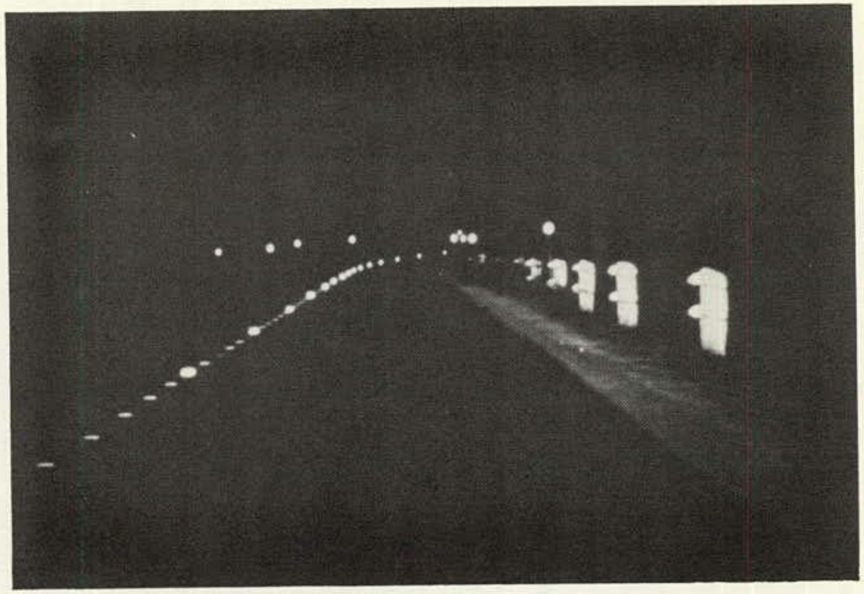

Figure 18 Non-reflectorized raised pavement markers spaced at 4 ft, with high-intensity markers spaced at 24 ft.

Figure 19. Post delineators at horizontal curve to the left—outside only.

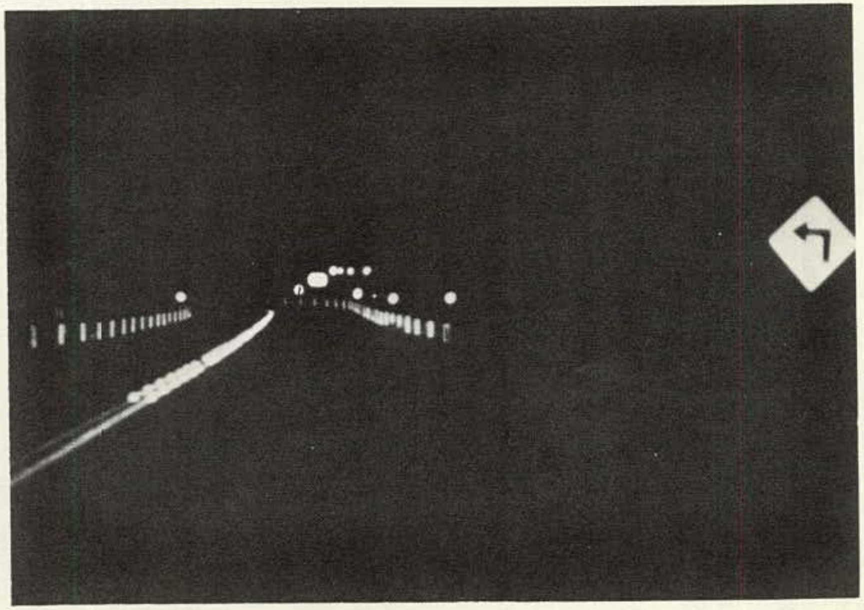

Figure 20 Raised pavement markers at a horizontal curve.

expense may not be justified on the tangent sections. (See Fig. 20.) They serve as far delineation, with good visibility distance and correspondence to the roadway path. They also are excellent near delineation treatments, providing strong improvements in lateral placement patterns.

3. The color of the raised pavement markers should be the same as the pavement markings they are supplementing.

4. Where raised pavement markers have been used, they have been popular with the driving public.

Rumble Strips

1. On very sharp curves where an accident problem exists, use of transverse rumble patches is recommended. (See Fig. 21.) Patches consisting of a series of transverse spray thermoplastic strips, 6 in. wide with 6-in. spacings, are effective and not objectionable. These lines hold up well under snowplowing. A set of three of the patches on each approach is suggested.

NO-PASSING ZONES

Pavement Markings

1. Use of the transitional marking mentioned earlier is recommended; i.e., a relatively open broken line should be used where passing is permitted, changing to a stronger line on the approach to a no-passing area, then finally to a solid line. Drivers would be permitted to cross the heavy broken line, but not the solid line. The problem of long-zone concept versus short-zone concept is philosophical and legal, rather than one of marking per se.

2. Improvements in driver behavior at no-passing zones are more likely to be derived from improvements in signing than from changes in pavement markings. Information that a no-passing zone is ahead is the critical need.

Post Delineators

1. It is not likely that an effective, intrinsic post delineator code can be developed for this situation. Therefore, application of this treatment to the no-passing situation was not considered further.

Raised Pavement Markers

1. The colors of the markers used should agree with those used for standard painted pavement markings, so that the treatment can be easily and unmistakenly identified.

2. Daytime raised pavement marker patterns should simulate the painted pavement markings in comparable situations.

3. At night, the change in marker patterns for this situation would be from white markers at relatively long spacings to yellow markers at short spacings. Thus, the raised pavement markers will be considerably more effective than pavement markings in providing information as to the location of upcoming no-passing zones.

4. Use of yellow markers in a solid-line pattern in areas where white markers are not being used on the standard sections will also be effective, and provide some advance warning.

PAVEMENT WIDTH TRANSITIONS

Increases in width are not a major problem, as failure to recognize this situation on approach is not likely to result in troublesome driver behavior. Most of the following comments are, therefore, more pertinent to width reductions, where more severe consequences may result if the information needs are not met.

Signing is also of considerable importance in this situation.

Pavement Markings

1. Painted arrows in the lane being dropped are suggested.

2. Edge lines should be continued, or added if nonexistent on the approach.

3. Yellow zebra-stripes in the taper area of width reductions should be heavy. In this project, a strong correlation was noted between density and effectiveness in moving traffic off the marked area.

4. Use of heavy lines (8 in. wide, with approximately equal length of mark and gap) will be helpful on approaches to the lane-drop ramp situation. (See Fig. 22.) This will direct the driver's attention to the fact that he is in an unusual situation—he will be able to determine the nature of the situation from other cues.

Post Delineators

1. Shortening of the spacing of post delineators in the area of the pavement width reduction will emphasize a feeling of constriction, and changing the color (from crystal to amber under present usage) will provide advance warning of change. (See Fig. 23.)

2. Use of post delineators on both sides of the road will further emphasize constriction, and promote slower and more attentive approaches. (Amber is recommended for the left side, but crystal is acceptable.)

3. This is one situation where post delineators with daytime visibility may be beneficial, as the environmental cues are often missing. Striped panels are suggested if a problem exists during daylight hours. (See Fig. 24.)

Raised Pavement Markers

1. Where a lane is dropped, the lane line will disappear when its projection becomes an edge line. This will not provide sufficient warning in itself; it must be supplemented with post delineators and/or pavement markings.

Colored Pavement

1. Solid yellow-colored pavement is effective in moving traffic off the paved areas during daylight hours. The principal problems are low visibility at night, and degradation of color with weathering. Thus, colored pavements must be supplemented with other treatments.

Rumble Strips

1. Transverse rumble strips can be used to outline the taper area where a reduction in pavement width occurs; i.e., rumble would be felt when drivers left the proper path.

2. The rumble strip treatment should be used primarily as a supplement, where a problem persists after other treatments have been installed.

Figure 21. Rumble strips at a horizontal curve.

Figure 22. Pavement markings at lane-drop exit ramp, England.

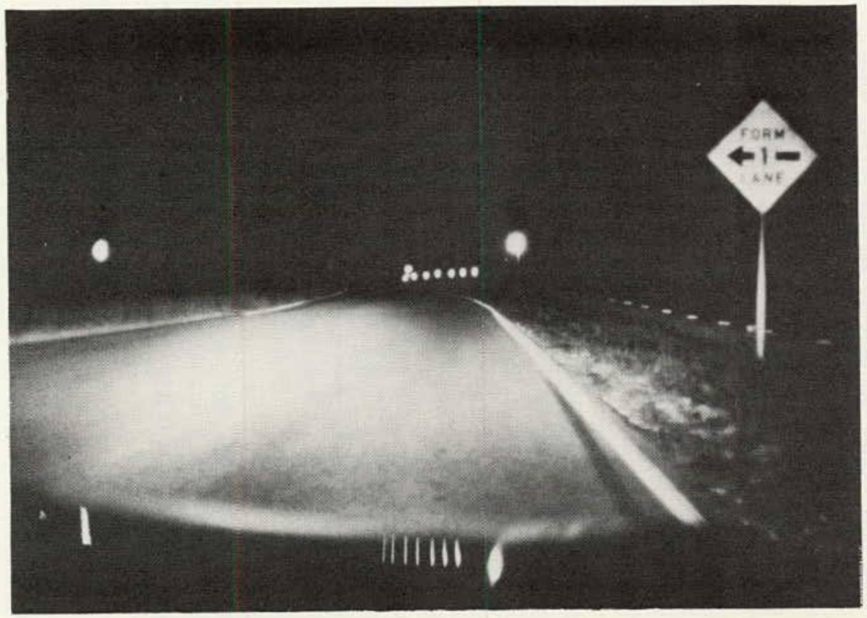

Figure 23. Post delineator treatment at lane drop.

Figure 24. Striped panels at pavement width transition.

MERGE AND DIVERGE AREAS

Pavement Markings

1. Discontinuous lanes (such as acceleration and deceleration lanes) should be separated from the through lanes by heavy broken lines; e.g., 8 in. wide, 10-ft mark with 10-ft gap. (See Fig. 22.) Thermoplastic markings should be given consideration for this application, as heavy wear will be encountered.

2. The heavy markings should be carried across the throats of exit and entrance ramps. This is especially important when ramps enter or leave curved sections of highway, as these lines can provide continuity of the edge line for the through driver.

3. The heavy broken line should also be used on the last 500 ft before the gore of other diverge areas, and on the first 500 ft of merged roadway, to indicate that lane changing is discouraged, but not forbidden.

4. It is important to maintain good edge lines on approaches to and exists from merge and diverge areas, as well as within the areas themselves.

5. Painted gore markings at exit ramps should be heavier than standard lines; 8- or 12-in. line is suggested. (See Fig. 25.)

Post Delineators

1. Delineators on ramps should have a different color from those used for the through lanes. Amber is generally used, but has the disadvantage that it is used for other purposes as well. Hence, the message is not unique and other cues are required before a driver is certain of the message. Also, use of amber along the right edge of deceleration or acceleration lanes contradicts the code that drivers are to stay to the right of yellow or amber markings. If crystal delineators are used for these situations, the advantage of color change is lost.

Several states have experimented with blue post delineators (and raised pavement markers) for delineation of ramp areas. No adverse effects are reported; however, in some cases no change in driver behavior was noted. Inasmuch as blue is not used for other purposes, a unique ramp message could be obtained.

2. Once the diverge area has been clearly established, it is desirable to discontinue the use of post delineators on the inside edge of curves (the right edge for standard exit ramps) as the sharp curvatures in these areas create considerable "clutter" and may distract from the definition of the geometry.

3. The post delineator spacing specifications in the *Manual of Uniform Traffic Control Devices* are adequate, and no changes are recommended.

4. Through-way delineation should be strengthened in exit ramp areas; i.e., the post delineator spacing should be reduced, and post delineators should be added to the left side of the roadway if there are none. Frequently, only the standard tangent delineation is used (e.g., crystal delineators, one or both sides, spaced at 200 to 500 ft) and this makes it difficult to discern the through-way in the presence of the much stronger exit ramp delineation.

5. An important cue in exit ramp situations is the color change at the point of the gore; i.e., where the line of delineators for the left edge of the ramp with one color meets the line of delineators for the right side of the through lane with another color.

6. Similarly, a change in color of the post delineators is an important cue at the end of a merging area, as it indicates that the conventional cross section has been reestablished.

Raised Pavement Markers

1. Where they can be used, raised pavement markers are an excellent treatment for diverge gore areas. (See Fig. 26.) They provide good advance warning, and definition of the geometry, due to their correspondence with the roadway. They may be color coded to indicate a changing situation. The rumble effect when crossing them warns drivers that they have strayed from the intended path.

2. A change in color of the ramp markers from the through-way delineation is important—the specific color is of secondary importance. Use of blue markers has the advantage of uniqueness, as opposed to yellow.

3. It is important to delineate the edge line of the through road on the approach to, and a short distance past, the gore or end of the merging lane to define the total geometry. If this is not done, the signal from the ramp or diverge lane overpowers that for the through lane and, although the ramp driver is comfortable in his exit maneuver, the through driver experiences some uncertainty.

4. Raised pavement markers should be supplemented with post delineators on vertical crest sections, which occur frequently in merge-diverge situations.

5. The raised pavement markers should be used on both edges of ramps or diverging roadways to define the "pathway to be driven within" rather than the "line to stay next to." (See Fig. 27.)

Colored Pavements

1. Colored pavements can be used to indicate desired pathways in complex situations and will improve driver performance when they are clearly visible.

2. The effectiveness of the colored pavement treatment is severely limited by lack of visibility at night, and loss of impact of color change with weathering. Its use is limited, therefore, to applications where daytime problems can be attributed to lack of definition of the pathway to be followed.

Systems

1. Diverge areas are particularly suitable for the application of delineation systems. It is possible to color code pavement markings, post delineators, raised pavement markers, colored pavement (if used), and signs to differentiate the two possible routes to follow through the diverge area. Limited experiments in this area have been reported (none was conducted in this project). In general, the installations have been limited to a few sites. As a result, the base is too small for meaningful comparisons of accident experience. Drivers generally report that they liked the system, or were not cognizant of it. Much larger

installations will be required before over-all effectiveness can be determined, but the systems have considerable intuitive appeal.

TURNS

The approaches to the intersection, channelization, and left-turn slots are the primary areas for application of delineation treatments at turn situations.

Pavement Markings

1. If the open broken-line pattern is adopted for the general center line, the warning line (greater mark-to-gap ratio) could be used to provide warning of the upcoming intersection. The solid line would still be used in the immediate intersection area.

2. A heavy broken line (8 in. wide; 10-ft mark to 10-ft gap) should be used to separate discontinuous lanes from through lanes; e.g., between left-turn slot and the through lanes. This will indicate to the driver that he is making a major change in his situation if he crosses this line.

3. California reports that pavement markings are as effective as raised islands for channelization in rural areas. No experimental data were obtained in this project, but this seems reasonable, and would eliminate the hazards inherent in raised obstacles in the roadway.

4. Pavement arrows give clear messages as to permissible movements at upcoming intersections. They should be used wherever there is any uncertainty as to the desired or permissible movements.

Post Delineators

1. The spacing of post delineators should be reduced to 50 ft for the last 500 ft on the approach to an intersection where turning maneuvers are heavy, to indicate need for extra caution. This treatment tends to create a restrictive effect, particularly if used on both sides of the roadway, and encourages caution. A change in color of the delineators in the intersection area from those used on the approach roadway is not recommended, as color change should be reserved to indicate transition sections (e.g., merge-diverge area, pavement width transition, stop approach).

Raised Pavement Markers

1. The spacing between raised pavement markers should be reduced in line with the recommendation for strengthening painted lines on the approach to intersections.

2. Closely spaced raised pavement markers are a good treatment for outlining channelization islands at night. Care should be taken to direct the reflective surface toward the driver, rather than parallel to the edge of the island. The reflective markers could supplement either painted islands or those formed from colored pavement. Yellow markers would be used in this application.

3. Closely spaced crystal raised pavement markers should be used between left-turn slots and through lanes in areas where these markers are used. A double row is suggested. It may be desirable to omit the raised pavement markers for the first 100 ft of the left-turn slot to permit traffic to get into the slot without crossing the markers themselves. This is somewhat inconsistent with recommendations for paint lines, but may be necessary due to the relatively short life of raised pavement markers when used where turning movements occur.

Colored Pavements

1. The use of colored pavements for left-turn slots is of marginal value. The best feature is that the use of colored pavement appears to discourage through traffic from entering the left-turn slot. Thus, the treatment may be useful where entry to the left-turn slot occurs at a left or right curve and following the center line may draw the through traffic into the slot. (However, heavy dashed pavement markings between the lanes may provide the same benefit.)

Due to the stronger negative signal than is obtained from pavement markings, the use of yellow-colored pavement to shadow the beginning of a left-turn slot is effective. Again, this must be supplemented by reflective yellow striping for nighttime visibility.

2. Colored pavement should be good for channelizing islands (not investigated in this project). Along with the strong negative message, the slight hump at the edge of the paved section will emphasize to the driver that he is straying from the design path.

Rumble Strips

1. Although rumble strips are too expensive to install and maintain as a general treatment, they could be used to shadow left-turn slots where experience indicates that encroachment by through traffic is a problem.

STOP APPROACHES

The STOP sign is the primary cue, of course. Frequently, however, it is hidden from view by trees, brush, and other signs until the driver is close to the cross road. This leaves no room for driver inattention, as he must act almost immediately upon sighting the sign.

However, the sign, even if visible, is not always sufficient. At many of the sites used for the colored pavement studies (which were selected by the Pennsylvania Department of Transportation as high-accident sites) the signs were clearly visible for long distances. A characteristic of many of these sites was that the "stopped" roadway had been a through roadway for several miles. It is theorized that the drivers do not notice the STOP sign because they expect a continuation of the right-of-way they have become accustomed to. Hence, extra measures are recommended where the STOP sign follows a long section of through roadway.

Pavement Markings

1. As in several situations mentioned previously, adoption of the open broken-line system will permit changing the center line to a warning pattern preceding the solid line on stop approaches.

2. Addition of edge lines where none exists on the approach roadway will promote a feeling of restriction,

Figure 25. Wide pavement markings at exit ramp gore area.

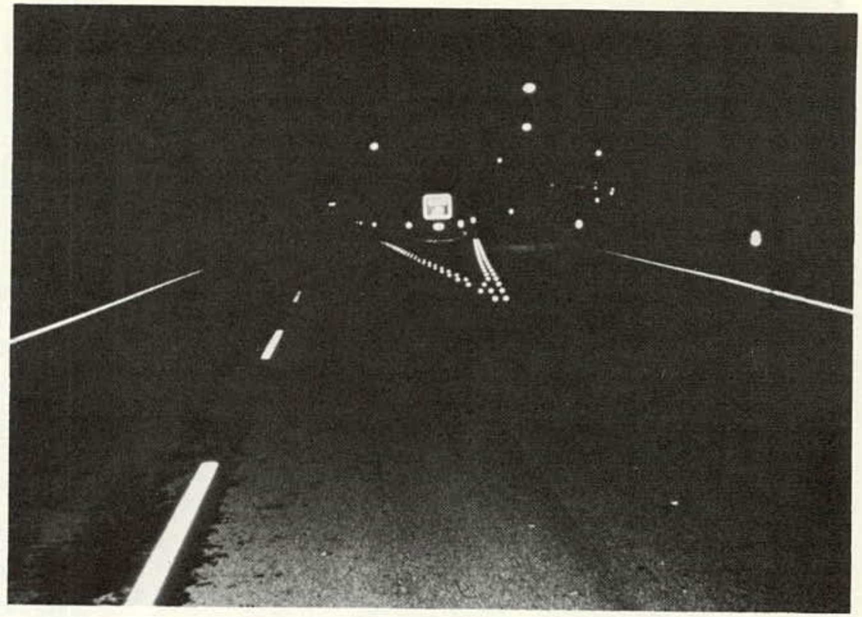

Figure 26. Raised pavement markers at an exit ramp gore area.

Figure 27. Dual line of raised pavement markers on exit ramp.

Figure 28. Post delineators at stop approach—progressively shorter spacings.

and the change will alert drivers to a changing situation. Experimental data derived in this project indicate that a two-line system, creating a tunnel effect, is highly desirable.

Post Delineators

1. Post delineators at progressively shorter spacings (from 200 ft or more down to 10 ft) on the approach to STOP signs were found to be effective in reducing approach speeds. (See Fig. 28.) This treatment tends to lead the driver's eye directly to the STOP sign.

2. Crystal post delineators were found to be at least as effective as red delineators as a stop approach treatment. Hence, crystal is recommended (to be consistent with the later recommendations for the use of raised pavement markers). The change in spacing is apparently sufficient change to draw attention. Although it would seem that red delineators would intrinsically convey the message better, they lack impact due to lower contrast with dark backgrounds, lower intensity, and the fact that many are used, in odd patterns and unusual situations, as driveway markers, etc.

3. The addition of post delineators, at progressively shorter spacings, on the left side of the roadway is recommended, as this treatment will provide a restrictive tunnel effect.

Raised Pavement Markers

1. The use of raised pavement markers at progressively shorter spacings on approaches to STOP signs is recommended. Because standard spacing is short compared to that for post delineators (e.g., 48 to 80 ft), two changes in spacing will be sufficient—20 ft for last 200 ft before the STOP sign, 40 ft for the next 320 ft, then the standard 80 ft is suggested. (When conventional spacing is 48 ft, changes to 24 ft and 12 ft should be used.)

2. Because red raised pavement markers have been used to designate "wrong way" on some freeway sections and ramps, they should not be used at stop approaches. Crystal should be used, relying for stimulus on the spacing change rather than the color.

3. The addition of raised pavement markers to the edge line for the section over which closer spacings on the center line are utilized will provide the tunnel effect. If post delineators are used on the same stop approach, the edge line raised pavement markers will add little to the over-all system, and can be deleted.

Colored Pavements

1. Red-colored pavement was shown to be effective in reducing approach speeds in situations where good visibility can be obtained. When daytime run-the-STOP-sign accidents are a problem, red-colored pavement may be an effective treatment, but it is not likely to be sufficient at night.

Rumble Strips

1. Although rumble strips are not suggested as a general treatment, they are effective for special problem areas, particularly in situations where the driver does not expect a STOP sign, such as after a long stretch of through roadway. Progressively closer spacings provide an extra stimulus—the driver gets the impression that he is accelerating if he does not decelerate in an appropriate manner.

CHAPTER FIVE

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Specific conclusions from the various study phases of this project are summarized in Chapter Two. The studies themselves are included in the Appendices. Chapter Four reflects the researchers' conclusions regarding the application of specific delineation treatments in the "classical" situations. More general conclusions, based on an overview of the total project, are as follows:

1. The literature review, the discussions with other researchers and practicing highway engineers, and the studies conducted in this project all suggest the conclusion that the major benefits derivable from delineation, in terms of accident reduction potential, can be obtained through widespread application of current standard treatments. Data from extensive long-term investigations (outside this project) indicate that statistically significant reductions in accident rates can be obtained through the application of delineation treatments where there were previously none; i.e., presence vs absence of specific delineation treatments can be related to accident rates.

Therefore, if accident reduction is the overriding criterion, the solution is fairly straightforward—provision of any good, standard treatment will provide virtually all the benefits obtainable from delineation.

2. Major changes in delineation treatments in specific situations can produce measurable changes in intermediate effectiveness criteria. The intermediate measures include erratic maneuvers and the means and variances of various

traffic performance measures, such as speeds, lateral placements, and points of brake application. It is hypothesized that the installation of treatments that reduce the number of erratic maneuvers and/or the variances of the traffic performance measures (indicating more uniform driving performance) will lead to a lower accident frequency. Hence, the relative effectiveness of major alternatives in delineation treatments can be evaluated through these intermediate measures. Almost certainly, however, factors other than safety will also influence the evaluation.

3. The intermediate effectiveness criteria are not sensitive enough to measure the effects of minor variants within treatments (spacings, brightness, most color codes, differences in materials, etc.) Diagnostic teams and driver surveys inherently evaluate factors other than accident reduction (e.g., driver ease and comfort, message clarity, aesthetics). Thus, it is possible to use these techniques to determine the relative effectiveness, in terms of these latter factors, of minor variants in the treatments.

4. In designing and specifying delineation treatments and systems, there should be far greater concern for compliance with a few basic principles than with minor variations in the treatments.

In general, both "far" and "near" delineation is required. Far delineation keeps the driver apprised of changing situations; post delineators are the most common form. Near delineation, on the other hand, provides the driver with information he needs to perform adjustive maneuvers and to maintain his desired travel path; pavement markings are the most common form. Raised pavement markers, where they can be used, provide both far and near delineation in a single treatment. This advantage is being recognized, and the use of these markers is growing rapidly where there is no need for snowplowing.

Other principles that deserve consideration include the desirability of two-line vs single-line systems, the need for minimization of clutter, the need for positive (as opposed to negative) delineation or at least suppression of negative delineation in the presence of positive delineation, and the need for simple intrinsic codes.

5. Inasmuch as minor variants in treatments do not measurably affect their effectiveness as accident reduction measures, least-cost solutions can receive more attention. More expensive variants of the treatments must be, and may well be, justified on other bases.

6. Reliance has been and will (and should) remain on subjective evaluation methods, because the accident reduction potential is nearly the same for all treatments in the same class and the non-accident factors are subjective by nature. The lack of a valid, reliable, and data-feasible cost-effective methodology is a further constraint on objective evaluation. Cost-effectiveness techniques can be used as aids in the decision-making process, but it will be difficult to arrive at convincing benefit/cost ratios if only direct "hard" benefits are included. In general, it will be better to use an approach similar to that outlined in Guideline Form III (Chapter Two) than to attempt to assign dollar values to the various indirect, intangible benefits.

7. Establishment of a Delineation Task Force, similar to the one in California, is likely to be the single "best move" by any state highway department in the field of delineation. This task force is essentially a diagnostic team, and the advantages and limitations of this approach are outlined in Appendix T.

It is important that this task force should include traffic engineering personnel from the divisions, as well as from the central office. The maintenance, materials testing, and design departments should also be represented. As the functioning of this group is dependent on subjective opinions, it is essential that independent ratings and opinions be obtained, and that no single "strong" person control the group. Structured judgmental decisions, such as those outlined in the guideline forms of Chapter Two, are the preferred method, rather than a round-table discussion.

This group should meet at regular intervals, and be continuing in nature. This will permit evaluation of large numbers of diverse test installations and, perhaps most important of all, provide the impetus for continuing study of delineation problems within the state.

8. The major problems in implementing the findings, applications, and recommendations of this report, and in the general improvement of delineation practices are:

(a) The lack of clear-cut cost-effectiveness arguments. Considerable reliance must be placed on subjective evaluations of indirect benefits.

(b) Institutional constraints. In most states, the districts are relatively independent and may set their own priorities. The authority for design, installation, and maintenance of delineation treatments and systems may be divided among several persons within the agency.

SUGGESTED RESEARCH

Research directed toward the evaluation of the accident-reducing potential of minor changes in delineation treatments is not likely to be fruitful—the benefits from these changes will be "soft" and only subjective evaluations will be possible. However, continued research in the following areas is highly desirable, and meaningful advances can be expected:

1. An initial attempt at validating the relationship between intermediate measures and accident rates at horizontal curves is reported in Appendix Q. This work should be extended to other situations and other traffic performance measures.

2. A change in the broken-line patterns used for center lines and lane lines is recommended in Chapter Four. Support for these recommendations was derived from observation of practices in other countries (and discussions with traffic researchers there), and a limited amount of field study in this project. It is recommended that more extensive field studies be conducted in the United States to determine the optimum mark and gap lengths.

3. Subjective evaluations are likely to remain major considerations in arriving at delineation decisions. Hence, studies directed toward the improvement and strengthening of subjective evaluation techniques will be worthwhile.

4. Raised pavement markers provide good visibility on rainy nights, the most severe condition for reflective

markings. However, the common markers cannot be used where snowplows operate and studded tires are used. Although a few commercial firms are working on this problem, a totally satisfactory snowplowable marker (cost and performance) is not yet available. Considerable effort in the development of a snowplowable marker is warranted.

In addition, where appropriate, recommendations for the extension of the individual, more specific studies conducted in this project are included in the appropriate appendices.

APPENDIX A

DELINEATION SITUATIONS AND DRIVER INFORMATION REQUIREMENTS *

The structure of this appendix is based on the assumption that the report will be used in situation-specific terms; i.e., users will refer to the report when they have a specific curve, merging area, etc., or a particular section of roadway to delineate.

From this appendix, the user will be able to derive the information requirements pertinent to a specific situation and determine the current practices and thinking regarding delineation for these situations. (Standard practices, as described in the *Manual of Uniform Traffic Control Devices,* are not generally included in this appendix, on the assumption that the user is familiar with these practices. Research related to specific situations and unique applications of treatments is stressed.) Also, a synthesis and evaluation, with suggestions for needed research, is provided at the end of the discussion for each of the delineation situations.

In addition to the specific geometric situations, a section on general delineation considerations is provided. This section covers such items as edge lines, contrasting shoulders, and longitudinal line patterns, which prevail throughout many geometric situations.

General Comments on Models

The rationale behind the selection of the specific models presented in this appendix and the analytical approach used to define the driver's delineation information requirements are presented in Appendix B.

In all, seven situations were identified as having sufficiently unique requirements to justify full model development. These are:

1. Horizontal curves.
2. No-passing zones.
3. Pavement width transitions.
4. Merging-diverging areas.
5. Turns.
6. Turns with deceleration and/or storage lanes.
7. Stop approaches.

In addition, two other situations are presented—tangents; and railroad crossings, crosswalks, etc.—for which models were not developed because they would be trivial due to the nature of these particular situations.

Because the search for delineation information constitutes a subtask from the driver's point of view, the flow chart for each model is not restricted to delineation requirements only. That is to say, delineation information competes with other environmental stimuli, some of which are more critical to the maneuver, hence enjoy a higher priority in the total driving task. Effectiveness of the delineation treatment, therefore, is in part determined by its success in reordering the priority system.

Note that the left column on each chart (for an example, see Fig. A-4) specifies the particular information required. Proceeding to the right, the next column identifies the sources(s) of that information, followed by the task requirements. The latter constitute the actions required for the safe and efficient travel from one quasi-steady state to another, or alternatively, safe and efficient travel through a transitional situation.

One further point on the "Information Requirements Sequence" and "Information Sources" columns: it is clear that the driver is at all times engaged in maintaining his continuous adjustive control and must, therefore, constantly monitor other traffic. In developing the flow charts, one objective was to simplify the presentation; thus, e.g., "other traffic" as a source and "headway" as an information requirement were generally omitted unless the adjustive control behaviors occurred in what could be considered a critical interaction with other information. In the latter case, the "other traffic" notation is employed.

Evaluative measures for the assessment of effectiveness of various alternative delineation treatments at the given situation are listed in the last column of the flow chart.

Following each flow chart is a situational diagram showing the trajectory of an assumed subject vehicle. Critical events are noted on the diagram.

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Accidents

Although accidents are discussed in this appendix, it is not implied that this report presents a state-of-the-art summary in accident research. The accident data and comments presented here are generally limited to comments on accident experience as related to specific delineation treatments in the various situations, rather than comments on accidents in the situations themselves.

Two reports of particular relevance, to which readers are referred, are "Accident Rates as Related to Design Elements of Rural Highways," *NCHRP Report 47* (*32*), and "Evaluation of Criteria for Safety Improvements on the Highway," Roy Jorgensen and Associates (*348*).

A more general discussion of accidents as related to roadway delineation is presented in Appendix S.

Current Practices and Related Research

Following the situation models are paragraphs describing current practices and related research in areas relevant to the particular situation. These comments are presented concisely so that the reader can easily determine the source in order to make his own interpretation and evaluation. It is not intended that these discussions be exhaustive—but rather that new and/or unique findings be reported on the assumption that readers of this section will be familiar with standard treatments and applications.

Reference notes follow certain paragraphs that report specific comments, findings, or results from the literature, current practices interviews, or discussions with non-project personnel. The code for these reference notes is as follows:

First term: Issuing source of information. A state listing indicates that the information came from personnel of the named state highway department, or from research sponsored by that agency.

Second term: Date. In the case of a report, the publication date; in the case of an interview or discussion, the date of same.

Third term: The medium in which the information was transmitted to project personnel. The following codes are used:

A. Numbered documents (see Appendix V). The "A" is not used.
B. Current practices interview.
C. Internal reports and memos of highway departments, research organizations, etc.
D. Other discussions and interviews (e.g., unofficial interviews, talks with other researchers).
E. Project staff remarks.

Synthesis and Evaluation

At the end of the discussion for each situation, a synthesis and an evaluation of the information needs, current practices, and related research are presented. These interpretations represent the researchers' opinions and have evolved from discussions and the analysis of experimental programs throughout the project.

Suggested Research

Suggestions for needed research, by situation, are presented. It was not feasible to undertake all of these efforts in this project. However, the comprehensive list is provided to indicate the areas where information gaps exist and where future research would be most fruitful.

GENERAL DELINEATION CONSIDERATIONS

Driver Information Needs

The general human factors considerations behind the derivation of the driver's information needs and the analytical approach employed to specify those needs are covered in Appendix B. The needs for specific situations are covered in the later sections of this appendix. In addition, the reader is referred to Chapter Two for a discussion of driver information needs considerations not exclusively related to specific situations.

Non-specific Situations—Current Practices and Related Research

Many considerations related to delineation are not amenable to discussion by geometric situations. For example, edge lining is carried through tangent sections, vertical and horizontal curves, width transitions, etc. It would be more appropriate, therefore, to discuss this facet under its own heading rather than under each situation. Many other problems and treatments also apply to several situations, such as contrasting shoulder treatments and the problem of spacing pavement markers to simulate longitudinal patterns. This section, therefore, is devoted to these non-specific situations and related delineation practices and/or treatments.

Edge Lines

Edge lining has become an accepted practice in nearly every state. Pavement edge marking is widely considered desirable for purposes of driver comfort and safety. Many traffic engineers believe that it provides the driver an additional guideline to follow and permits him to position his vehicle more centrally in the traveled lane. Almost without exception, the general public is enthusiastically in favor of edge lines.

Several states have investigated the effects of edge lining on driver behavior and accident experience. Some of their findings are reported as follows:

1. In 1954, Arizona first experimented with shoulder striping on two-lane 40-ft-crown-width rural roads. On one-half of a 30-mile test section they applied a dashed white edge line (7 ft long with 33-ft gap). No edge line was provided on the other 15-mile section. Willey reported that the number of accidents on the edge line section was only one-fifth of those on the other section. In addition, the greatest volume of vehicles traveled a mean center of gravity distance of 11 ft from the center line with shoulder stripes as compared to 10 ft without shoulder stripes. (Arizona, 1954, *100*)

2. During 1956, the Louisiana Department of Highways conducted a number of studies to determine the effect of

pavement edge striping on the lateral placement of vehicles on 24-ft-wide tangent sections of highway. Both continuous and dashed edge lines were investigated. Thomas concluded that edge lining had no effect on vehicle placement during the day, but at night the continuous line tended to move vehicles slightly toward the center line. (Louisiana, 1956, *19*)

3. In 1957, Louisiana repeated the placement study on 24-ft tangent highways in a different part of the state to verify findings of the initial study and added tangent sections of 20-ft roadways as well as 4-lane divided highways with 12-ft lanes in one direction and 10-ft lanes in the other. Thomas and Taylor make the following conclusions:

(a) The 1956 and 1957 studies indicate strongly that free-flowing vehicles on a 24-ft highway marked with a center line and an outside continuous line will travel several inches closer to the center line.

(b) On 20-ft tangent roadway, where vehicles travel nearer to the center line initially because the roadway is narrower, the trend is still to move toward the center line after painting of the continuous edge line.

(c) On 4-lane divided highways completely different findings were observed for vehicles moving in the 12-ft lanes as compared to those in the 10-ft lanes. With 12-ft lanes, the edge stripe moved vehicles in the outside lane toward the lane line, whereas the continuous line along the median moved vehicles away from the lane line and toward the median. This movement was almost 1 ft at night. On the 10-ft lanes the edge stripe along the outside edge and the median moved vehicles in both lanes toward the lane line.

(d) Based on these studies, Louisiana has adopted a policy of edge striping all 24-ft, two-lane highways, but will not mark two-lane highways that are narrower than 24 ft.

It should be noted that in all cases, shoulders were in color contrast to the through roadways. (Louisiana, 1957, *20*)

4. In 1957, Halverson reported on Utah's early experience with right shoulder edge lines. During the study period, three types of accidents were significantly reduced after edge lining: head-ons, sideswipe (overtaking), and running-off-the-roadway. (Utah, 1957, *6*)

5. In 1957, the Ohio Department of Highways conducted a controlled before-and-after study on the effects of pavement edge markings on the accident patterns on two-lane rural highways. Both the before and the after study periods were one year long. Statistical analyses of the reported accidents yielded the following results:

(a) On two-lane rural highways in Ohio, use of pavement edge markings resulted in a statistically significant reduction in fatal and injury-causing accidents.

(b) Accidents at intersections, alleys, and driveways were significantly reduced, but accidents between access points showed no significant change.

(c) The only type of collision to show a significant change (a substantial reduction) was the angle collision, which is associated with access points. (Ohio, 1957, *10*)

6. Williston, while investigating Connecticut's use of yellow reflectorized edge lines on two-lane and four-lane divided roads, arrived at the following conclusions:

(a) The presence of a painted line along the outer edge of pavement affects the lateral position of vehicles. During darkness, the addition of edge markings tends to position free-moving vehicles more centrally in the marked lane.

(b) On the Merritt Parkway, a four-lane divided highway, run-off-road accidents attributed to driver inattentiveness were substantially reduced with the presence of edge lining. (Connecticut, 1960, *23*)

7. In 1960, the Kansas State Highway Commission conducted a study to determine what effect edge markings may have on accident rates on two-lane rural highways. Using a controlled type of before-and-after accident comparison study, Basile offered the following significant conclusions:

(a) On two-lane rural highways in Kansas, the use of pavement edge markings resulted in a reduction in the number of fatalities.

(b) There was no significant change in number of persons injured or in total number of accidents.

(c) Accidents at intersections and driveways were significantly reduced under both daytime and nighttime conditions. Accidents between access points were not significantly reduced. (Kansas, 1960, *2*)

8. Tamburri, et al., report a significant reduction in run-off-road accident rates with the installation of 2-in.-wide right edge lining on 72 miles of two-lane highways in California. (California, 1968, *36*)

9. Missouri used a before-and-after study to determine some of the effects of edge line striping on driver behavior for rural two-lane highways. Lateral placement, vehicular speeds, and driver comfort (galvanic skin response) were used as a basis for measurement. It was concluded that in the presence of an edge line, vehicles generally tended to move closer to the center line, especially during darkness. Speeds were not significantly changed during the study and the results of the galvanic skin response analysis were inconclusive. (Missouri, 1969, *9*).

10. Schepp and Lamb studied various methods of delineation markings to discourage encroachment on paved 8½-ft shoulders. A notable difference in lateral position was recorded between the 30° diagonal striping and other patterns tried. It also appeared that diagonal shoulder markings had more effect in eliminating random shoulder encroachment during the dark than during daytime. (Wyoming, 1965, *35*)

Synthesis and Evaluation.—The majority of the states use edge lining to some extent on their rural two-lane roads. (A notable exception is Texas, which uses edge lines very little in any situation, depending on contrasting shoulder treatment for edge delineation.) Most state specifications do not permit edge lining of pavements narrower than 22 ft.

The comparative accident studies previously mentioned indicate that edge lining is effective in reducing accidents. The results of the studies in Ohio and Kansas are somewhat surprising in that they indicate that accidents are reduced at access points, but not between them. Most of the accident studies are fairly short in both time period and roadway mileage investigated.

The Ohio study theorizes that edge lines cause drivers to look farther down the road and increases their awareness of vehicles entering from the sides. A recent study of polarized headlighting points out that, in the opposed glare condition, pavement edge markings provide approximately 500 ft of additional "far" delineation. This may account for the popularity of edge lines, because they aid the driver in one of the critical driving situations. The additional available guidance may also be an accident reduction factor.

Several studies indicate that edge lining does affect the lateral placement of vehicles, particularly at night. However, the reported results are sometimes contradictory and it does not appear that anyone has established a correlation between lateral placement and accident experience; i.e., even if lateral placement can be affected, what is the desirable placement and is edge lining cost-effective?

A special problem in edge lining is the two-lane 40-ft-crown-width roadways in the West. The principal question is whether the edge lining should be at the edges of the roadway (i.e., 20 ft from the center line) or approximately 13 ft from the center line, thereby delineating the intended shoulder area. This problem is discussed in more detail under "Wide Two-Lane Roads" later in this section.

More attention is given to edge lining in European countries and Japan. Wide edge lines are used extensively and several different patterns have been utilized. (See Appendix D for details of edge lining treatments in other countries.)

Suggested Research.—Determination of the effect of edge lines on lateral placements under various geometries would be a relatively simple task. Therefore, research directed toward the establishment of potential accident reduction as a function of lateral placement would seem to be fruitful.

Another research program of value would be the use of eye movement measurement equipment to determine the validity of the Ohio conclusion that edge striping causes the driver to look farther down the road, thereby reducing access point accidents.

Contrasting Shoulders

Contrasting shoulders are employed for two-lane rural highways in many states, particularly in the West. In general, shoulder treatment in the East on two-lane rural highways is relatively poor, and little effort to install effective contrast treatments has been noted.

At least one state (Texas) believes that contrasting shoulder treatment is adequate to delineate the edge of the roadway and consequently does not use painted edge lines. One Texas Highway Department official expressed the belief that edge lines are not economical. He admits that people like them, but considers them "window dressing." He believes they are expensive and that the money could be used to better advantage in other ways.

When new, good contrasting shoulder treatment is dramatic (see Fig. C-17). In some circumstances, however, contrasting shoulders are not effective. Many pavements that show good contrast during the day lose that advantage on a rainy night. (Of course, painted edge lines are not effective on rainy nights either.) Also, the color of the original pavement and/or shoulder often changes with time. Occasionally the two become indistinguishable after a relatively short service life.

The European countries and Japan make extensive use of contrasting shoulder materials and color, usually in conjunction with edge lines (sometimes quite wide). These edge lining treatments are not always paint. In Germany, for instance, an asphaltic concrete roadway might be bordered by an 18-in. strip of portland cement concrete and then by asphaltic concrete or a chip-seal shoulder.

Synthesis and Evaluation.—Although contrasting shoulder treatments are used extensively, there is little research reported in the literature to relate the use of such treatments to accident experience or driver performance of any sort. It is another treatment that most people agree is "intuitively good," but for which there appears to be no "hard" data available to justify any added expense.

Longitudinal Lines

The patterns to be employed when using raised pavement markers need considerable attention, in the opinion of several highway engineers. In particular, they believe that it is often difficult to differentiate between solid and broken lines using the present patterns. Line patterns simulated by variations in density of markers are fairly effective during the daytime, but the solution at night is not clear, inasmuch as nighttime reflective markers are generally installed at fairly large spacings (48 ft and 80 ft are common examples) for cost considerations and because smaller spacings are not required to delineate the roadway path.

1. In Texas, the standard pattern for lane lines is six ceramic markers spaced at 3 ft to give a 15-ft mark followed by a 25-ft gap. Reflective markers are used in the center of every other gap (80-ft spacing). (Texas, 1969, B)
2. California uses a 9-ft paint line with a 15-ft gap for dashed lines. When raised pavement markers are used the 9-ft line is simulated by four ceramic markers spaced at 3 ft. Reflective markers are usually set in alternate gaps, or at a spacing of 48 ft. On sharp horizontal curves, the reflective markers are sometimes used at every gap, or a spacing of 24 ft. (California, 1969, B)
3. It is claimed that the patterns of raised pavement markers used in California and Texas tend to look like solid lines when viewed at some distance down the road. Field observation indicates that the same is true of dashed painted lines. In one situation, where it was possible to observe both painted and ceramic marker dotted lines, they seemed to merge into a solid line at about the same distance from the driver. (E)
4. California has investigated several techniques for using raised pavement markers on right edge lines. To

date, they have not found a satisfactory solution. They believe that these lines may be more important than the lane lines or left edge lines in terms of accident reduction. (California, 1969, B)

5. As a result of observation of a series of experimental installations of raised pavement markers in California, the Delineation Task Force of that state made the following recommendations concerning special-purpose line patterns:

(a) *No-passing stripes*—The task force recommends use of a pattern consisting of reflective markers at 24-ft centers interspaced with plain yellow ceramic markers at 3-ft centers.

(b) *Median edge lines*—The task force recommends use of single rows of reflective markers at 24-ft centers on PCC pavements and the same spacing interspaced with plain yellow markers at 6-ft centers on all black pavements.

(c) *Ramp edge lines*—The task force has completed a considerable amount of experimentation on this item. The recommended pattern is a "blue tunnel" of blue reflective markers formed by placing markers on both sides of the ramps and on the right edges of the main traveled ways immediately adjacent to the ramp throats.

(d) *Right-hand edge lines*—The task force found that each time reflectors were placed on the right edge of travel ways an undesirable feeling of lateral restriction was conveyed to drivers. No installation recommendation has been made to date, but further study is under way to determine whether a series of plain wedge-shaped markers on the right edge will provide the needed delineation and act as a rumble strip deterrent to go-to-sleep, run-off-the-road-type accidents. (California, 1967, D)

Another item brought up frequently by traffic engineers in various interviews and in meetings is the "correctness" of the present dashed line patterns. The standard pattern employs a 3:5 mark-to-gap ratio; several engineers theorize that this ratio could be increased—i.e., less paint could be used without decreasing the effectiveness. It appears that the current practices are based on historical usage, and little experimentation in this area has been reported.

1. A Japanese study indicated that at 50 mph a mark-to-gap ratio of 2:3 gave the visual appearance of 1:1. On that basis, they have revised their paint line practice from a 1:1 to a 2:3 pattern. However, this is based on the assumption that a line pattern that appears to be 1:1 is somehow desirable. (D)

2. England, which uses only white paint, must depend on line patterns considerably more than the various States. For a discussion of line pattern practices in various other countries, see Appendix D.

3. A pilot study utilizing a 5-ft mark and 35-ft gap was conducted in this project. Details and results are given in Appendix O.

Synthesis and Evaluation.—Although the subject has been discussed fairly frequently, little research has been directed toward the effect of varying longitudinal line patterns. It seems generally agreed that the present patterns are effective, but that perhaps equal effectiveness could be provided at lower costs. Hence, it is suggested that research in this area be directed toward cost reduction while maintaining present effectiveness, rather than toward increasing effectiveness.

Wide Two-Lane Roads

In the Western states, two-lane highways with 40-ft crown widths (frequently with full structural strength throughout) are utilized. At present, two general philosophies regarding the use of edge lines on these roads are in existence and roadways have been marked in both manners.

One group believes that the edge lines should be put at the edge of the pavement (i.e., roughly 20 ft from the center line), with the entire lane width used as a travel way. They observe that slower moving traffic generally moves to the right to let the faster traffic by. Due to the width of the lane, the passing traffic does not encroach on the opposite lane by much. Thus, a pass can be negotiated even if there is traffic coming from the opposite direction. In a sense, then, three-lane operation is possible. They claim that experience shows this operation to be satisfactory and that accident rates are low. Against the argument that encroachment on the opposite lane is bad when opposing traffic can be seen, they counter that the reduction in the number of drivers who are impatient due to being trapped behind a slower moving vehicle reduces the frequency of high-risk passing situations that otherwise occur.

On the other side, a second group claims that the edge line should be approximately 12 or 13 ft from the center line, providing a 7- or 8-ft shoulder. As previously mentioned, it is their claim that passing should be discouraged in the face of oncoming traffic. Also, they believe that drivers will use the outside edge of the pavement for emergency stopping and they should be "shadowed" from the through traffic by the edge line. Otherwise, the following driver may not note that the vehicle ahead is stopped until it is too late.

This edge line placement problem on the wide two-lane roadways has not been resolved to the satisfaction of most engineers. Several have taken sides on the question, but most admit that they do not have research results to back up their opinions and indicate that they could be convinced of the alternate marking technique if an adequate study were conducted and reported.

Texas is experimenting with a new delineation technique for wide two-lane roadways, as indicated in Figure A-1. The standard two-lane roadway has a 44-ft crown. Initially, this was divided into two 12-ft lanes with 10-ft shoulders. As a result of vehicle placement studies, which showed that 13-ft lanes gave better placement (i.e., more separation between opposing lanes of traffic), there has been a tendency toward use of 13-ft lanes with 9-ft shoulders.

Recently, Texas has used a 4-ft painted median for wide two-lane roads, resulting in two 12-ft lanes separated by a 4-ft median, with 8-ft shoulders. This painted median consists of either two solid 3- or 4-in. lines or two skip

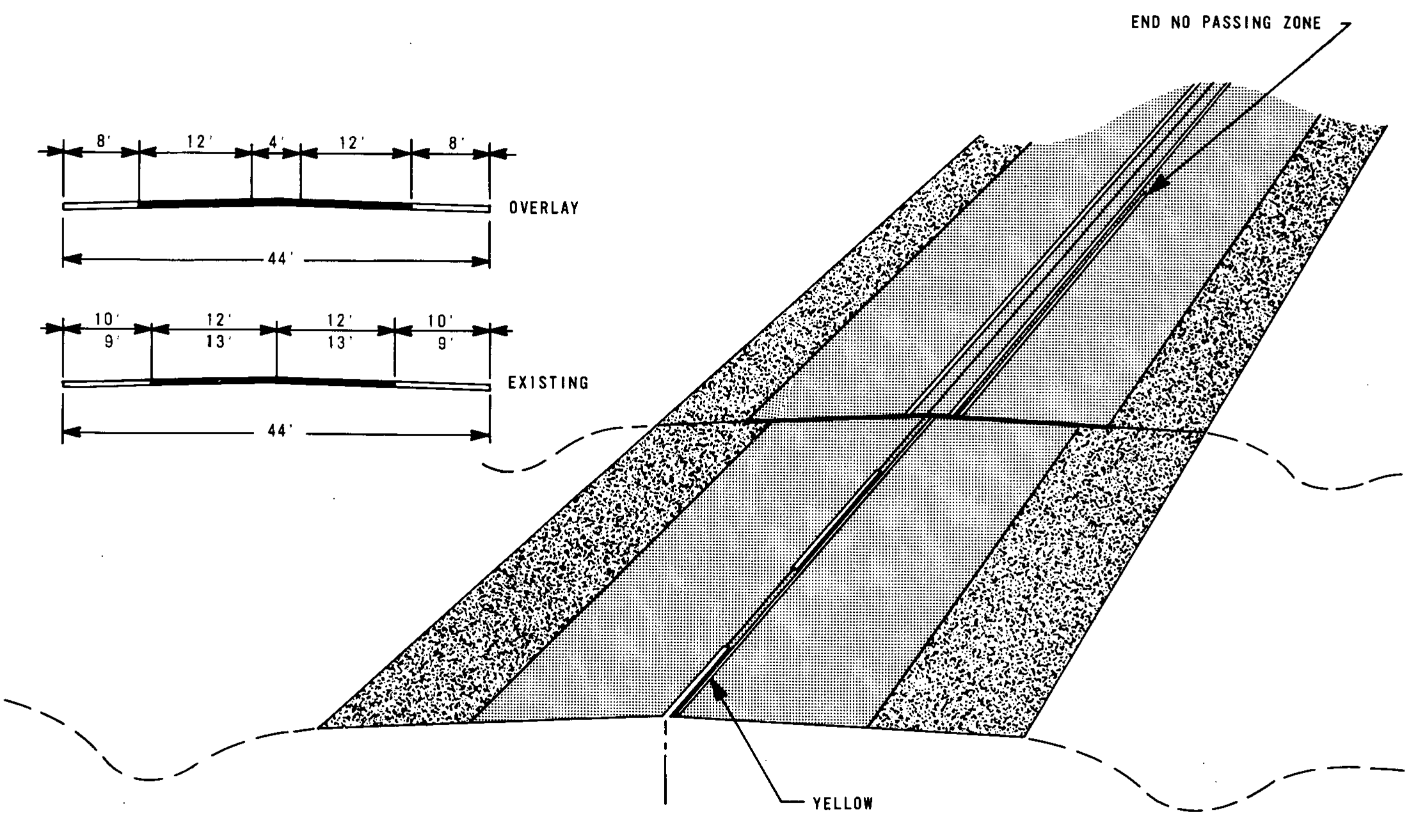

Figure A-1. New pavement marking technique for wide two-lane roadways, Texas.

lines. Operationally, with standard markings, drivers tend to move out when they meet opposing traffic and then come back into the center of their lane. On the "new" design, traffic tends to center on the proper lane and stay there when passing opposing traffic. This conclusion is supported by study of movie films of actual traffic operations. From observation, drivers appear to regard the double solid line or double skip line in the same manner. Texas prefers the double skip line.

With the new design a car following a truck can pull out far enough to look ahead without getting into any real trouble. Left turners tend to use the 4-ft median as a storage lane and the other cars pass them on the right. One-year accident records on a few short sections (a total of perhaps 20 miles) show no head-on accidents.

Texas has also used a 2½-ft spacing in the median in order to retain 8-ft shoulders when the crown was narrower. This treatment seems to be equally effective.

A no-passing stripe is applied in the same manner as the regular design. On passing sections, drivers cross this double center line with no apparent reluctance. (Texas, 1969, B)

Suggested Research.—An extensive investigation of the pros and cons of the argument for placement of the edge line on wide two-lane pavements should be conducted. It is possible that accident records are available for a sufficient time and length of roadway such that conclusions could be drawn from analysis of these records. However, it may be necessary to study the operations of traffic on these as an intermediate step and then establish the relation between these operations and potential accident rates.

The new marking technique being initiated in Texas should be followed closely. There are many roadways, particularly in the West, that could be re-striped in this manner if it is proved desirable. Again, intuitively, the wider separation of opposing traffic lanes has appeal, because it would permit larger driver error without involvement in an accident. On the other hand, perhaps anyone who strays across a center line would also continue on across this painted, but otherwise traversable, median.

Climbing Lanes

Frequently, climbing lanes for slow-moving traffic are terminated immediately over the crest. This is an undesirable practice, as it forces the slow-moving drivers over into the path of the faster-moving vehicles just as they pass over the crest. Hence, the faster driver may find a slow-moving vehicle in his lane just as he comes over the crest, where his sight distance has been at a minimum.

California is experimenting with the use of 8-in. "elephant track" lines (3-ft mark, with 12-ft gap) for truck

Figure A-2. "Elephant-track" markings for climbing lanes, California.

climbing lanes. (See Fig. A-2.) An inspection of a study site by a group concerned with delineation practice yielded conflicting opinions as to whether or not there was a discernible difference between the "elephant tracks" and the adjacent lane line. The intention in this experimental program was merely to convey to the driver the message that there is "something different about this lane" in order to move slow traffic to the right and yet permit traffic trapped in that lane to feel free to leave the auxiliary lane. California is also considering the use of a solid 8-in. line in this same situation. (California, 1969, B)

Inadequate Design

Frequently, delineation is used to compensate for inadequate geometric conditions. For instance, Figure A-3 shows a fairly common situation. The paved shoulder is not carried through the bridge, resulting in a "necking down" of the roadway as it crosses the bridge. Delineation treatments having high attention value are required in this case to warn the drivers that the shoulder is not available at the bridge.

Tamburri, et al., reporting on California's minor improvement program, indicated that the property-damage-only accident rate decreased significantly when reflectorized guide markers were placed on the left and right sides of approaches to 99 bridges located on a two-lane desert highway. Also, night accidents decreased from 20 to 10, but this was not considered statistically significant by the authors. (California, 1968, *36*)

Of course, delineation cannot fully compensate for inadequate design; however, since design changes are not always economically feasible (except over long periods of time) the need to treat such situations will continue to exist. It is difficult to assess the state of the art in this area, because the situations encountered vary considerably, solutions generally involve a collection of treatments, and the results are rarely reported in the general literature. Effective problem solutions will come from the application of general delineation concepts and modification of the treatments used in standard situations.

Figure A-3. Loss of crown width through bridge.

TANGENTS

Driver Information Needs

Under the situation classifications scheme developed in Appendix B, tangents can be categorized as quasi-steady-state situations. Briefly, this means that the driver's task requirements are limited to maintaining continuous adjustive control, both lateral and longitudinal. More specifically, the driver must attend to headway maintenance and lane placement.

In comparison with the so-called transitional situations, the tracking task and the information processing functions are considerably less complex; hence, there was no need to develop a full detailed model. A model developed for this situation would almost certainly be characterized by a marked lack of change and would, therefore, be somewhat trivial.

Current Practices and Related Research

Many of the items reported in the following do not apply to tangent sections of highway exclusively. In a sense, however, the treatments and/or applications were designed for tangent sections and then were continued through the other geometric situations. The discussions are not repeated in the succeeding sections of the report dealing with other geometric situations.

See Colo. Std. Dwng S-614-51A (1972)

? 1. Colorado uses post delineators on one side of the roadway only. Highway department personnel believe that delineators used in this manner are more successful in their purpose and less confusing to the driver, besides being more economical. On tangent sections, they generally space the delineators 400 ft apart. (Colorado, 1969, B)

2. In 1963, Arizona reported on the results of a study to determine the cost and relative effectiveness of defining the edge of pavement with steel post-mounted delineator plates as compared with a 4-in. white shoulder stripe. The reflectorized delineator plates were located only 18 in. from the pavement edge and spaced 400 ft apart. On critical geometries the spacing was reduced such that at least three plates were visible at all times. The conclusions from a study of accident experience, vehicle speeds, and lateral placement of vehicles were as follows:

(a) Night speeds increased when roadway delineation was installed and the increase was greater for the shoulder striped sections than for the post delineator sections (5.9 mph vs 3.4 mph average increase).

(b) There is no significant difference between shoulder stripe and post delineators with respect to vehicle placement, day or night.

(c) Neither shoulder striping nor post delineators had any deterrent effect on accident occurrence under the conditions of the study.

(d) Although the initial installation cost was higher for post delineators ($146.11 per mile of post delineators vs $117.97 per mile of stripe) the annual maintenance was substantially less ($18.55 per mile of post delineators vs $124.40 per mile of stripe). (Arizona, 1963, *41*)

3. A Louisiana study, reported by Dart in 1965, evaluated the effectiveness of roadside delineators and edge lining on Interstate highways. The study was conducted on gentle curved sections as well as on tangents. Analysis of the data showed no significant effect of delineation on vehicle placement or on mean speeds. Results of driver interviews indicate that drivers of passenger vehicles at night are almost unanimous in their belief that roadside delineation is helpful to their driving on the Interstate highway. (Louisiana, 1965, *4*)

4. One state highway official expressed the opinion that there is a tendency to use too many post delineators and that they tend to clutter the highway scene. One reason for such "clutter" is that a large percentage of the markers are not for guidance, but serve to identify pipe crossings, mileposts, culverts, and survey monuments. These extraneous markers frequently result in a confusing pattern of post delineators even though the guidance markers are precisely located according to an accepted formula. Field observations have shown that when extraneous (i.e., non-guidance) reflectors are covered or removed, the night delineation picture is immediately clarified. (California, 1969, B) (For an example, see Figs. A-6 and A-7.)

5. Medians should give both visual and vibratile warning of encroachment, yet permit safe transverse crossing at drives, private entrances, etc. Striping of the area with paint is considered unsatisfactory because paint weathers, wears off, and is often undetectable during inclement weather. A more suitable means would be the use of a raised bituminous marker (rumble strip) to physically warn of encroachment. (Illinois, 1954, *73*)

6. White post delineators, along with white 4-in. edge lines, were used in Michigan on tangents between interchanges to denote the "through" roadway. One of the results of this treatment, when used in conjunction with color coding for ramps, was a decrease in erratic movements. (Michigan, 1967, *3*)

7. A system of reflectorized lane lines, edge lines, and single white reflectors on a turnpike tangent was tried with different levels of illumination. The reflectors were of 3-in. diameter and spaced at 200-ft intervals. The study did not show any significant change in average speeds, placements, and clearances for the various conditions of illumination and delineation. (Connecticut, 1960, *55*)

Synthesis and Evaluation

The two most common forms of delineation on tangents are the post-mounted delineators and pavement-level marking with paint or raised pavement markers. Because delineation can do little to provide information for the driver with respect to headway maintenance, the information needs served by delineation on tangents are principally lateral control requirements. The highest percentage of fixation points for driving a tangent appear to be from 75 ft to 100 ft in advance of a vehicle traveling at 50 mph. Thus, as far as lateral control is concerned, striping would appear to be an adequate information transfer technique. However, some question might be raised with respect to post delineators, due to the criticality of the spacing and their non-correspondence with the roadway surface.

Inasmuch as center lines are required in any case, the only additional delineation treatment to be considered in terms of longitudinal striping is the use of edge lines. To date, edge lines in the U.S. have been painted, as no pattern of raised pavement markers has been considered satisfactory.

Results comparing the post-mounted delineators with edge lines are conflicting in that several studies report no difference in vehicle speeds or placements between the two treatments, whereas others show no effect on placement but higher speeds using paint stripes. Higher speeds may imply greater driver comfort, but should not be interpreted as good in all circumstances. For instance, better delineation, resulting in higher speeds, may increase the probability and severity of accidents in foggy areas.

From the cost standpoint, it would seem more economical to use the post delineators than edge striping on tangents. Even though the installation cost is higher, maintenance costs on paint are generally much higher.

One of the more confusing aspects of tangent delineation is the use of amber post-mounted reflective delineators to mark pipe crossings, culverts, drainage ditches, and other roadside obstructions. Placement of the amber delineators often confuses the through pattern provided by the clear delineators. This confusion could arise from the specific location of the delineators, the color, or a combination of both, because the color is used also to provide information on entrance and exit paths at intersections.

Some of the techniques used to provide delineation in periods of inclement weather include curb marker lights that orient the driver in the fog, and raised bituminous markers (rumble strips) to warn the drivers of areas where median encroachments or intersection conflicts are imminent.

Until recently, California mounted their reflective delineators on a white rectangular background. These so-called "paddles" (the background plates) were originally installed to provide daytime delineation. There is a growing belief, however, that not only are these aesthetically unappealing, but that they also are unnecessary because daytime delineation on the California roadway system is generally not required. (Note paddles in Fig. A-2.)

Suggested Research

There appear to be few delineation problems that are unique to tangent sections of roadway. Those areas of research suggested in the previous section entitled "General Delineation Considerations" also apply to tangent sections, of course, and are not repeated here. Similarly, the no-passing zone, which also may occur on tangent sections, is covered in a subsequent section.

Several traffic engineers have expressed the opinion that a single line of delineation at night is undesirable (i.e., the use of post delineators on one side of the road only, or the use of reflectorized raised pavement markers in a single line). It is their contention that the driver loses his spatial orientation with time and that two reflectorized lines should be used at all times. It is believed that painted lines do not provide the second line, as they are visible for only relatively short distances. On the other hand, the cost for the two-line systems is obviously higher, and research is needed to establish the cost-effectiveness relationship.

Another possible problem with raised markers is the increased potential for the so-called "highway hypnosis" effect at night. The markers will appear as a relatively bright point source of light; thus, the degree to which the "hypnosis" effect is a problem with current markings will be magnified with such stimuli. Although admittedly the problem would be extremely difficult to research, the problem bears consideration if extensive use is contemplated.

HORIZONTAL CURVES

Driver Information Needs

As discussed in the introduction to this appendix, the driver's delineation needs for most of the geometric situations are presented in the form of flow charts and maneuver (or "ideal") path diagrams. The flow chart and the maneuver diagram for horizontal curves are shown in Figures A-4 and A-5.

Referring to the maneuver diagram, the only signing assumptions in this example are an advance warning of curve sign, placed 750 ft in advance of the point of curvature, and an advisory speed sign placed at the point of curvature. To provide a reasonable scale, a degree of curvature, $D = 7°$, and a length of the curve, $S = 350$ ft, were assumed in constructing the diagram.

Current Practices and Related Research

The warrants and practices regarding the installation of post delineators on curves on rural two-lane highways vary considerably from state to state and even from district to district within states. Almost all states provide post delineators at "hazardous locations," but in many cases signs are the only warning or guidance provided.

1. California uses a simple white paddle mounted on a timber or steel post with a reflector attached to the paddle to delineate the road. Tamburri, et al., reported on the effectiveness of these guidemarkers in preventing accidents on curves of various radii. Of the five radii classifications only "500 (ft) or less" showed a significant decrease in total accident rates. This result led to the warrant of delineation on curves of 500-ft radius or less. (California, 1968, *36*)

2. Taylor and Foody, Ohio Department of Highways, conducted research to determine the parameters to be used in establishing warrants for post delineation on curved rural highways. The conclusions drawn from their statistical study are:

   (a) The present program of curve delineation (i.e., using 5° or greater as a warrant for delineation) in Ohio is effective but not efficient.
   (b) The degree of curvature alone is not a sufficient parameter for establishing delineation warrants.
   (c) The central angle provides a better measure of delineation effectiveness than does the degree of curvature. (Ohio, 1966, *17*)

3. Yu recently reported on a study to determine the relative effectiveness of several representative types of ma-

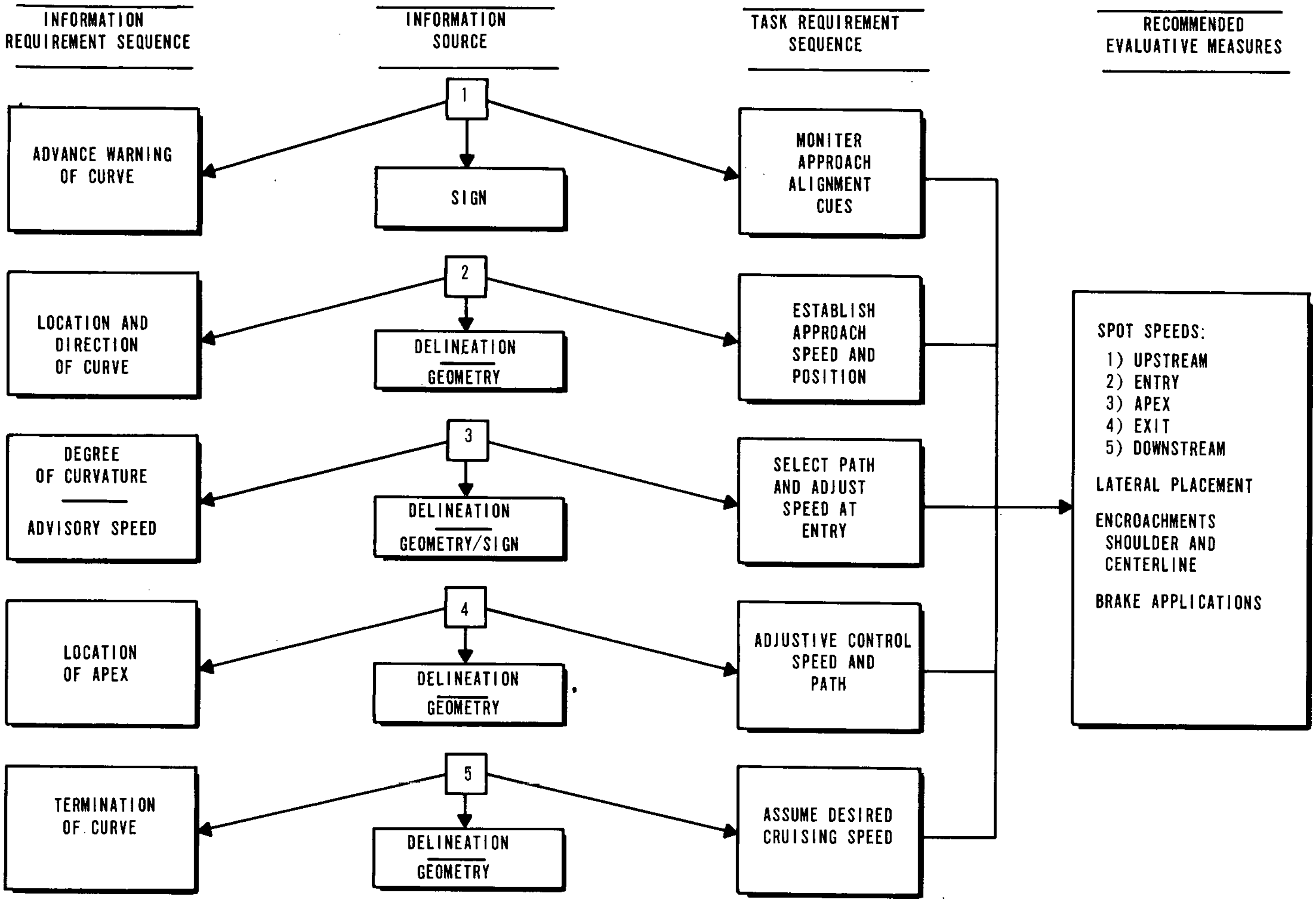

Figure A-4. Flow chart for horizontal curve.

terials used for median delineation on a curved section. The four types of materials were:

(a) Reflective paint.
(b) Reflective sheeting plate.
(c) Glass reflector.
(d) Mold-acrylic retro-reflector.

The distance at which the study material became visible to the approaching driver was assumed to be the best indication of relative effectiveness of the materials studied. The reflective materials studied were found to be significantly different from one another under both clear and inclement weather conditions. The rank orders of their effectiveness were (1) glass reflectors, (2) reflective sheeting plates, (3) acrylic retro-reflectors, and (4) reflective paint. (Yu, 1969, *40*)

4. Idaho evaluated the effectiveness of post delineators in reducing "left roadway" types of accidents for 47 delineation projects over a combined length of 559 miles of rural highways. The results of their 24-month before-and-after study showed that accidents were significantly reduced on curved sections at night. On the basis of safety alone (i.e., reduced accidents), a program of reflectorized delineators would yield negative benefits. However, other factors, such as driving comfort and motorist preference, should be considered. (Idaho, 1969, *8*)

5. Observations indicate that the use of post delineators on horizontal curves is not consistent in most states visited by the researchers. Several horizontal curves of fair degree of curvature were noted where no post delineators were used—frequently the very next curve did use post delineators. It may be that there is a radius of curvature warrant that is not obvious to the driver, or perhaps the delineators were installed in special high-accident locations. (E)

6. Frequently post delineators are used on the right side of the road only, even when the curve is to the right. At night this results in relative motion of the delineators as the driver approaches the curve—i.e., the delineators at the beginning of the curve will appear to be to the right of those in the central part of the curve initially, and then they will appear to move to the left of those in the center part of the curve as the driver enters the curve. Also, fewer delineators will be visible at any given time than if they were utilized on the outside of the curve. (E)

7. Montana places post delineators on the outside of all curves that are sharper than 4°. (Montana, 1969, B)

8. A traffic engineer in California suggested that post delineators be spaced on horizontal curves by the formula spacing without adjustment for varying curvatures at the ends—i.e., the run-in varying spacings at the ends of the curves should be eliminated; they add to installation complexity and detract from over-all appearance. (California, 1969, B)

9. California does not alter the spacing of non-reflective ceramic raised pavement markers on curved sections. They do, however, place a reflective marker in the middle of each gap, instead of every other gap as is the practice on tangent sections. (California, 1968, *53*)

10. Even the strongest proponents of raised pavement markers conclude that they are not sufficient delineation on horizontal curves, particularly those associated with crest vertical curves. They believe that post delineators or guardrail reflectors are still required. (E)

11. Curb marker lights, reported in more detail in Appendix C, were also used on curves in a study by Finch. Based on the findings, it is recommended that they be spaced 10 to 15 ft for long-radius (3,000 to 5,000 ft) curves and 8 to 10 ft for sharp curves (500- to 1,500-ft radius). (California, 1962, *50*)

12. In an Indiana study, both edge lines and supplemental delineators were placed on a hazardous curve approaching an intersection. In addition, directional and warning signs were improved. Speed profiles taken before and after the changes showed no significant difference. However, the number of accidents was reduced from 23 to 16 during the study period. (Indiana, 1961, *13*)

Synthesis and Evaluation

Although horizontal curves have received considerable attention from traffic engineers and researchers, the efforts have been characterized by applications and evaluations of standard treatments without regard to some of the conceptual problems involved in the total delineation process. These conceptual problems include the necessity and/or desirability of double lines for guidance (as discussed under "Tangents, Suggested Research"), negative vs positive delineation, and visual "clutter."

From the driver's point of view, the tracking task is quite taxing in the horizontal curve situation. For example, the task requirement sequence shows that adjustive control behavior is the principal action in traversing the curve situation. Guidance for these continuous adjustments is provided primarily by the geometry of the situation (i.e., the edge of the pavement) in the daytime. In addition to the location and direction of the curve and the degree of curvature, the driver gets some indication of the location of the apex (the point at which corrective action on adjustive maneuvers begins to occur) and some information as to the superelevation of the curve. Standard curve delineation does not, in the nighttime situation, provide adequate advance information regarding the last two items (i.e., the apex and superelevation). This could be critical information on substandard designs on rural curves of short radius.

Post delineators and longitudinal striping (paint and raised pavement markers) appear to be the most common forms of delineation treatment for curves. A serious question exists, however, on the proper method of installation. Taylor and Foody (*17*) suggest, for example, that although the degree of curvature warrants are effective, they are not efficient. They further suggest that the central angle may be a better warrant base than degree of curvature.

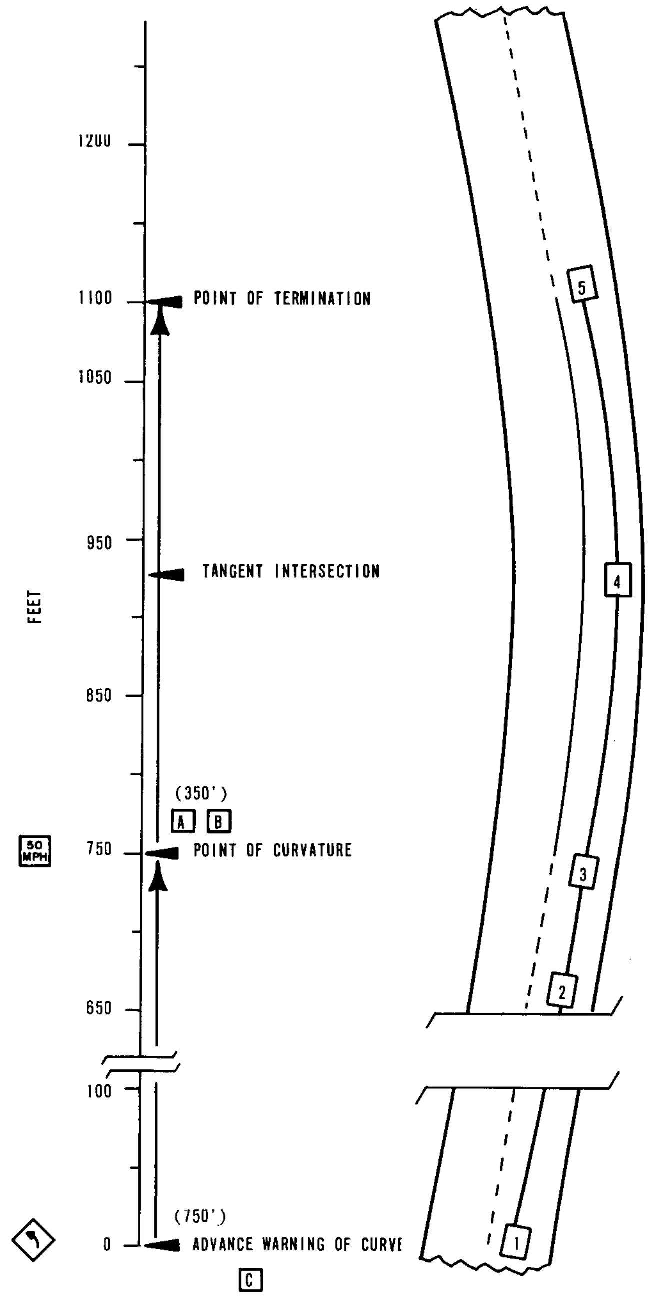

Figure A-5. Maneuver diagram for horizontal curve.

It would appear that the basic problem in determining the most effective delineation treatment for curves is in the measures of effectiveness that have been used. Yu (*40*), for example, in evaluating materials for delineating curves, defines effectiveness as approach visibility. Still, another study in Indiana, which involved the complete "overhaul" of a horizontal curve with new edge lines, post delineators, and improved signs, showed no difference in operational parameters such as speed profiles, but accidents were reduced during the study period. Although no definitive information is available as to the statistical reliability of the accident reduction difference, the Indiana study does point out the discrepancies that abound in selecting measures of effectiveness. It may be, for example, that increases in approach visibility are not necessarily improvements in effectiveness—it can be argued that improved delineation invites people to drive at higher speeds due to increases in "visual comfort." This may result in a false sense of security and may result in unsafe excess speeds for certain situations.

Suggested Research

One of the most serious requirements in delineation research is the specification of rational, and accepted, techniques for the evaluation of the effectiveness of alternative treatments. Of the rural, two-lane highway situations, the horizontal curve is probably best suited for evaluating alternative research techniques—the situation can be simply defined, the driver's task is straightforward and little divergence of opinion exists as to the proper maneuver. Details of a study relating various intermediate measures of traffic performance to accident rates are given in Appendix Q.

The concepts and problems listed in the following can be studied at horizontal curves. Some of these problems are unique to horizontal curves; in other cases, the horizontal curve provides a good situation for studying concepts that apply to several situations.

1. What is the effect of vertical alignment on the effectiveness of post delineators, paint lines, and raised pavement markers on horizontal curves?

2. Is "visual noise" or "clutter" a real problem? Some traffic engineers believe that there are too many post delineators on horizontal curves, particularly where they are used on both sides of the roadway. Has the claimed confusion and distraction created a significant safety factor, or can the extraneous delineators be removed from the warrants purely on the basis of cost-effectiveness? (See Figs. A-6 and A-7 for an illustration of the difference in appearance of delineation on both sides of a curve vs delineation on the outside only. The difference is considerably more dramatic when driving the route; i.e., when the visual input is dynamic rather than in the static mode illustrated here. In particular, the delineators on the right side of the road appear to shift with respect to each other and those on the left side of the road as the curve is approached.)

3. Coding is also of interest at horizontal curves. One proposal for the revised *Manual on Uniform Traffic Control Devices* called for use of yellow post delineators on the left side of curves. In that case, the delineators in Figure A-7 would be yellow and those on the left side in Figure A-6 would be yellow—thereby introducing a new dimension, and possibly confusion, as the whites and yellows intermingle on horizontal curves. On the other hand, the change in color between the two sides may be effective in aiding the driver to separate the two lines. (Field evaluations in the study described in Appendix M support the latter thesis.)

NO-PASSING ZONES

Driver Information Needs

The driver information needs are outlined in the flow chart and maneuver diagrams for the no-passing zone situation, as shown in Figures A-8 and A-9.

The passing maneuver illustrated consists of four elements. The initiation of the pass is at the occurrence of an END NO PASSING sign. Using the AASHO procedure, and assuming a reasonable passing speed of 53 mph, a total maneuver distance of 1,915 ft will be required.

Current Practices and Related Research

One of the primary problems in passing zones or no-passing zones is the transition between the two. Some engineers believe that there should be a transitional longitudinal marking from the passing zone to the no-passing zone, so that drivers considering a pass will be advised of the distance to a no-passing zone immediately ahead. This marking should be advisory in nature and would permit drivers already negotiating the pass a chance to return to their own lane without crossing the no-passing zone line. It would also prevent the driver in the process of passing from suddenly finding he is on the wrong side of a no-passing zone line (which is illegal in most states). A marking system of this type is recommended in Chapter Four.

1. Van Valkenburg and Michael, in their study of no-passing zones, note the inadequacy of the short zone concept that prohibits motorists from driving on the left side of a yellow line throughout the length of a no-passing zone. They propose an alternative—the long zone concept, which would allow crossing of the yellow line for the purpose of completing a passing maneuver. They developed criteria for marking no-passing zones and a model law required to implement the concept. (Indiana, 1971, *22*)

2. Short openings in the no-passing line should not be permitted. Often there is just a short distance between the end of one no-passing line and the beginning of another. Maintenance engineers should be empowered to paint continuous lines through these sections. (Texas, 1969, B)

3. For a no-passing zone on a bridge, no-passing barrier lines on the bridge approaches were extended and the bridge center lines and curbs were also painted yellow. Speed profiles did not change significantly, but minor increases in speed were noted at the critical zone. (Indiana, 1961, *13*)

4. The California Delineation Task Force determined, through extensive day and night observations of several different patterns of raised pavement markers, that a spacing of no more than 6 ft was required to simulate a solid stripe in the daytime. A 12-ft spacing was definitely not satisfactory; a 3-ft spacing gave an unmistakably solid appearance. The 3-ft spacing was adopted for the yellow

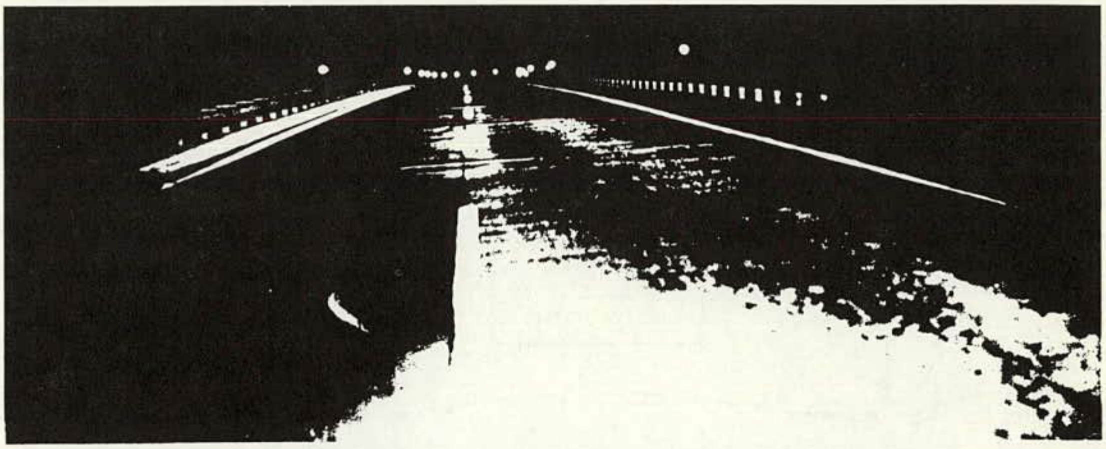

Figure A-6. Post delineators at horizontal curve to the right—both sides.

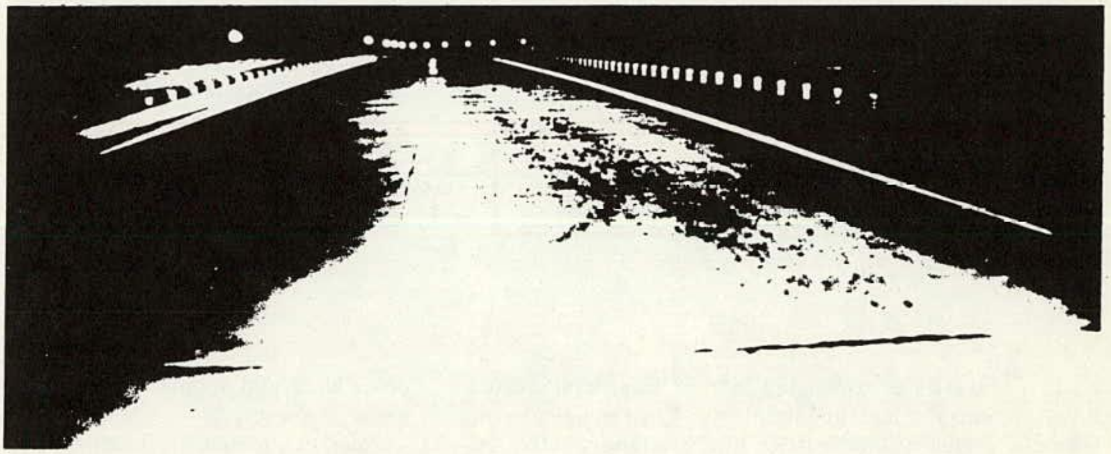

Figure A-7. Post delineators at horizontal curve to the right—left side only.

ceramic markers. Nighttime markers are installed at 24-ft spacings, one-half that of the standard lane line. (California, 1969, B)

Synthesis and Evaluation

In a sense, no problem exists at no-passing zones themselves, as the maneuvers are constrained to placement within the approved lane. Hence, the discussion should center around passing zones, with particular emphasis on those sections of road just prior to no-passing zones.

The passing zone situation, interspersed with no-passing zones, is frequently encountered on rural two-lane roads. It is generally used as a safety valve of sorts to provide the driver with an opportunity to maintain his desired cruising speed. Where pavement width and sight distance characteristics are adequate, interruptions in the solid yellow barrier lines in the form of a white broken line pattern are among the more recognizable delineation treatments that the driver experiences.

Although exposure has contributed to the certainty with which the driver recognizes the passing opportunity, no such certainty exists in either his decision to accept the opportunity or, given acceptance, how he manages to effect the passing maneuver. It would appear from recent experimental results that sight distance per se is the most influential factor in determining whether or not the driver will attempt a pass. In restricted sight distance situations, Hostetter, et al. (*136*) have demonstrated that only a small percentage of drivers who are given the opportunity to pass after being impeded over 1 to 5 miles will accept that opportunity, despite the fact that no oncoming vehicles are in sight (e.g., at 929-ft sight distance only 5.2 percent of the passing opportunities were accepted).

In another controlled field experiment, Hemstra (*134*) found that when a judgment of clearance time was required, most drivers were not capable of making it with any degree of accuracy. Taken together, these studies suggest that the warrants for marking zones for passing are not consistent with most driver's conservative risk-taking behavior in the passing situation. Conversely, drivers do

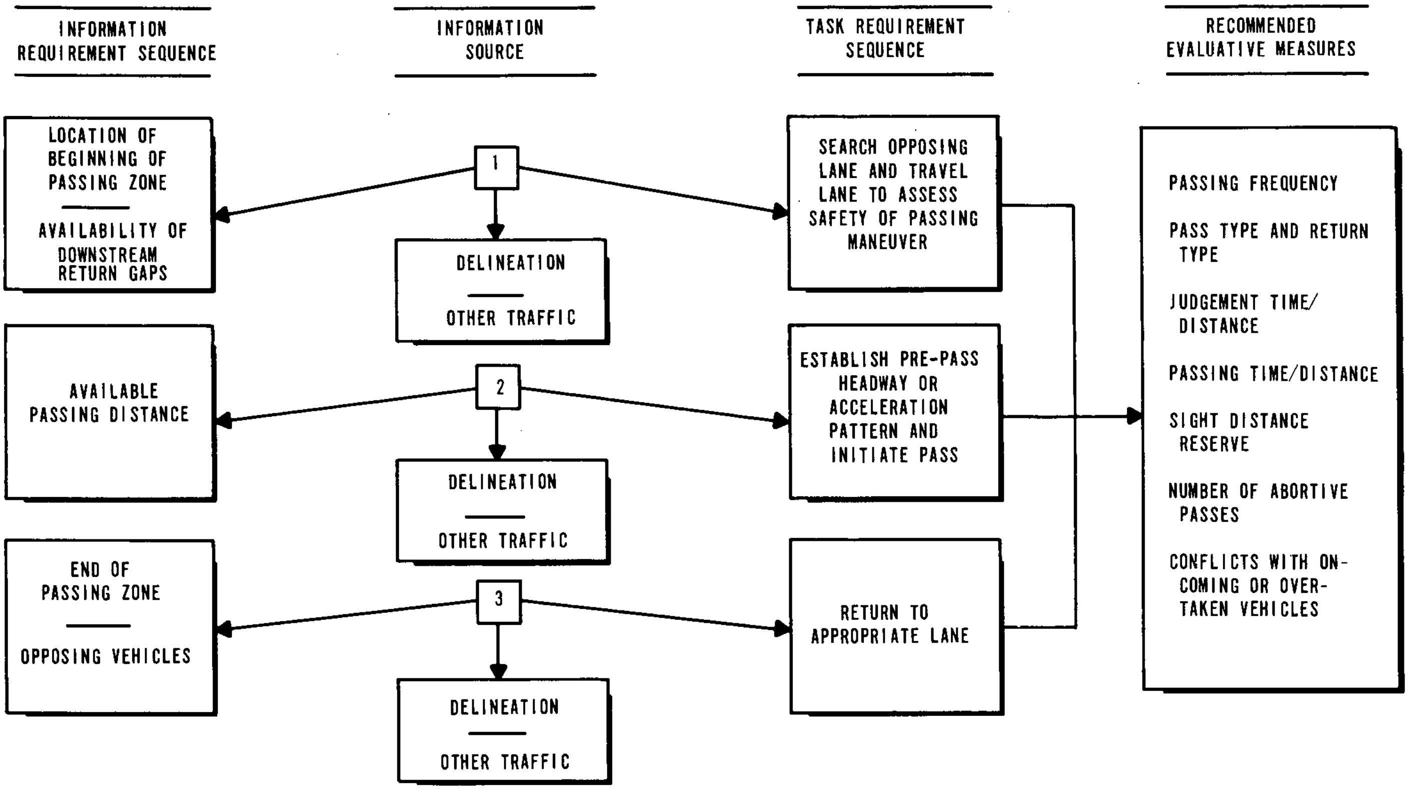

Figure A-8. Flow chart for no-passing zone.

tend to observe the no-passing barrier lines despite oftentimes inconsistent legal requirements. For example, in one state the double yellow barrier line is advisory only. Although there is nothing illegal about a pass in this particular state, drivers seldom realize that the action of passing is discretionary, because law enforcement officials tend to interpret any passing behavior in the double-yellow-line situation as reckless driving.

Perhaps the most serious informational deficit, and particularly serious under the reduced visibility conditions of nighttime driving, is the lack of a reference to indicate the beginning of the no-passing zone. Schmidt (*149*), for example, shows that the thresholds for judging displacement and movement increase from 4 to 10 times, respectively, in the absence of a reference point. Thus, at nighttime the lack of geometric and/or roadside cues does not permit the driver to make accurate estimates of closing rates or sight distance reserve that under ordinary daytime driving conditions would be provided by the relative motion between oncoming vehicles, the vehicle attempting to pass, and the selected physical reference in the immediate environment.

Still another deficiency in current warrants for marking no-passing zones occurs in areas where the passing opportunity is coincident with a sag vertical curve. Increasing numbers of low-profile cars reduce driver eye heights and so restrict the respective sight distance to the point where opposing traffic in the dip may go undetected. Thus, a need exists to reevaluate sight distance measurement procedures and minimum requirements for marking no-passing zones.

Another problem in the application of no-passing zones is the presence of slow-moving vehicles, such as farm tractors and heavily laden trucks. In these cases, the driver of a vehicle with high acceleration can, perhaps, pass safely, particularly in the early "stages" of the no-passing zone. As drivers have a tendency to obey only those regulations that seem reasonable to them, a large number of illegal, but reasonable, passes can be expected in this situation.

Drivers tend to estimate distance more effectively than time. It would seem, therefore, that any planned improvements in delineating no-passing zones should almost certainly involve some advance information component that designates to the driver the end of the passing opportunity. Michigan is investigating the use of pennant-shaped signs on the left edge of the road to inform drivers of upcoming no-passing zones. It may be that signing holds more promise in solving this particular problem than does variation in delineation patterns.

Suggested Research

Studies applied to the passing zone, no-passing zone situations are needed in the following areas:

1. Feasibility of providing some intermediate delineation (possibly long lines with short gaps, as used in England and recommended in Chapter Four) to inform the drivers of the transition from passing zone to no-passing zone.

2. Investigation into the desirability of making no-passing zone lines advisory, rather than considering all vehicles left of these lines as having committed an illegal maneuver. (The major problem, in this particular study, may be political in that enforcement officials much prefer a clear-cut ruling.)

3. Another question that deserves field evaluation is the deterrent effect of the rumble experienced in the lane-changing maneuver in areas where raised pavement markers are used. This could have significance in both passing zone and no-passing zone situations.

PAVEMENT WIDTH TRANSITIONS

Driver Information Needs

The driver information needs in the pavement width transition, including lane drops, are presented in the flow chart and maneuver diagrams shown in Figures A-10 and A-11.

The example illustrates a drop in the number of travel lanes from three to two. A total length of 400 ft is assumed for illustrative purposes.

Current Practices and Related Research

One of the more striking results of the literature review was that very little material, published or otherwise, deals with a common and critical situation—i.e., the pavement width transition. Perhaps the lack of attention given to pavement width transitions, per se, is attributable to the sizeable efforts that have dealt with other maneuvers which, in a subordinated fashion, have included the width transitions. Typical of these are acceleration lanes, entrance ramps, and auxiliary or climbing lanes. Usually, when engineers discuss this general situation, they refer to the frequently encountered reduction in the number of freeway lanes illustrated by the classical situation diagram shown in Figure A-11.

1. California (and other states) frequently uses a series of arrows to indicate that traffic should move out of a lane being dropped or that two lanes merge into one (or three lanes into two). (California, 1969, B)

2. In Canada, edge lines (not generally used on tangent sections) are applied at pavement width transitions. Also, the spacing of post delineators is decreased to 30 ft from the 200-ft spacing used on tangent sections.

3. An unusual treatment was noted in California where, due to stage construction, two lanes of a freeway had to be narrowed to one at the end of the completed section. The posts for post delineators were embedded in the pavement (see Fig. A-12). The treatment is reported to be highly satisfactory. In this case, daytime delineation is needed to alert the driver to the unusual situation, and the "paddles" normally considered to be unnecessary and unaesthetic are, in this case, desirable. (California, 1969, B)

4. An unusual situation, involving two lane drops without actual pavement width transition, occurs in Pennsylvania (see Fig. A-13.) In this situation, yellow zebra strips have been used in an attempt to move traffic to the left, out of a continuous paved lane. The treatment works well for the through drivers; i.e., they do move to the left, thereby moving away from the off-ramp and into the through lanes. However, it was observed that the local drivers, who are familiar with the situation, tend to drive over the yellow zebra striping in surprising numbers. For instance, local traffic approaching from the bottom of the figure and leaving the off-ramp frequently passes over both sections of the yellow zebra striping. Even more consist-

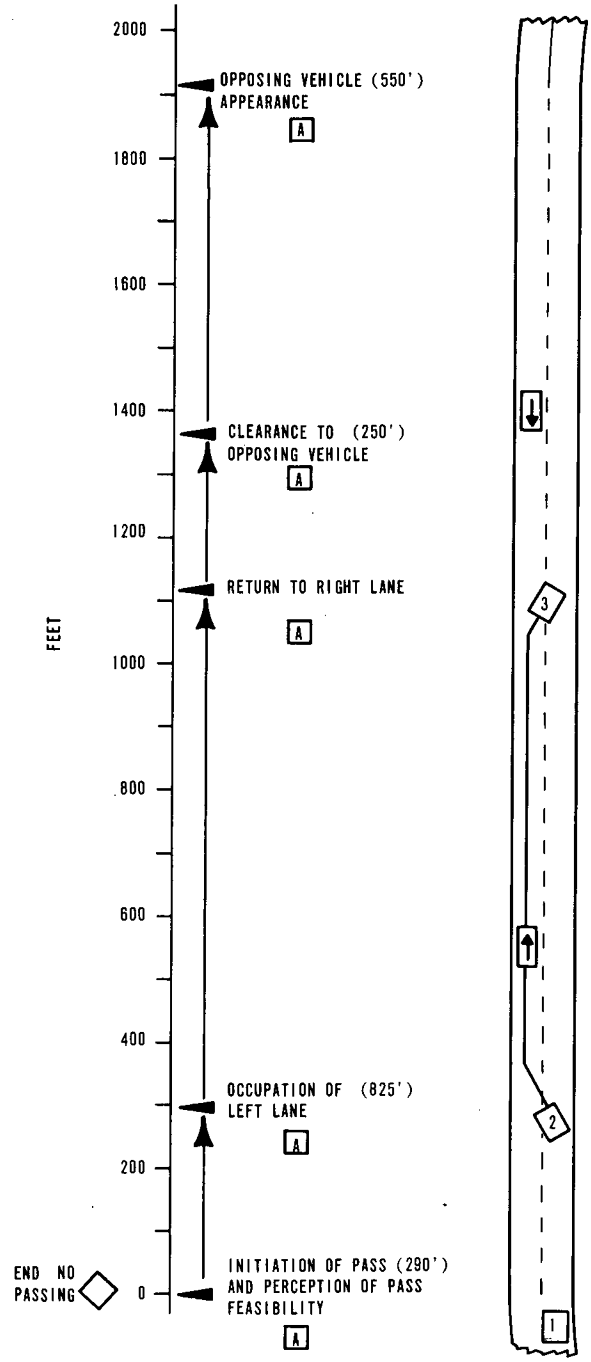

Figure A-9. Maneuver diagram for passing maneuver (1,915 ft).

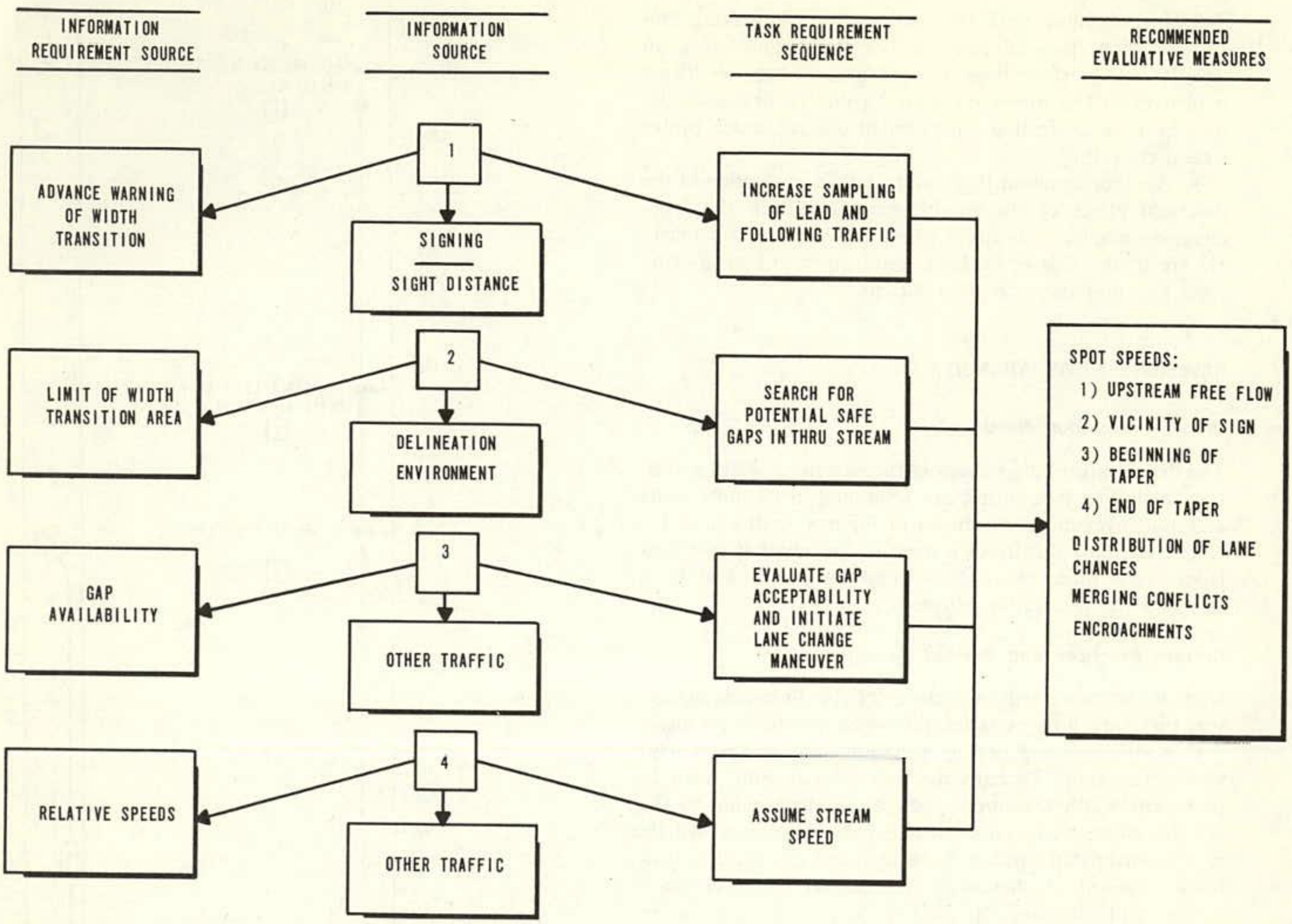

Figure A-10. Flow chart for pavement width transition.

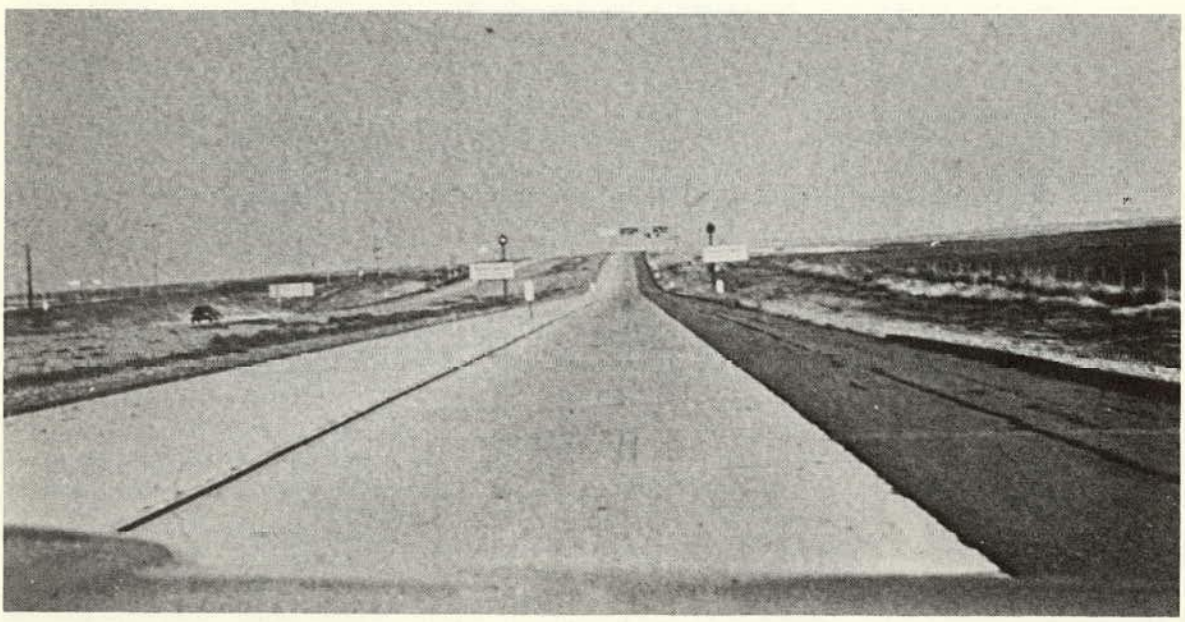

Figure A-12. Left lane drop, California.

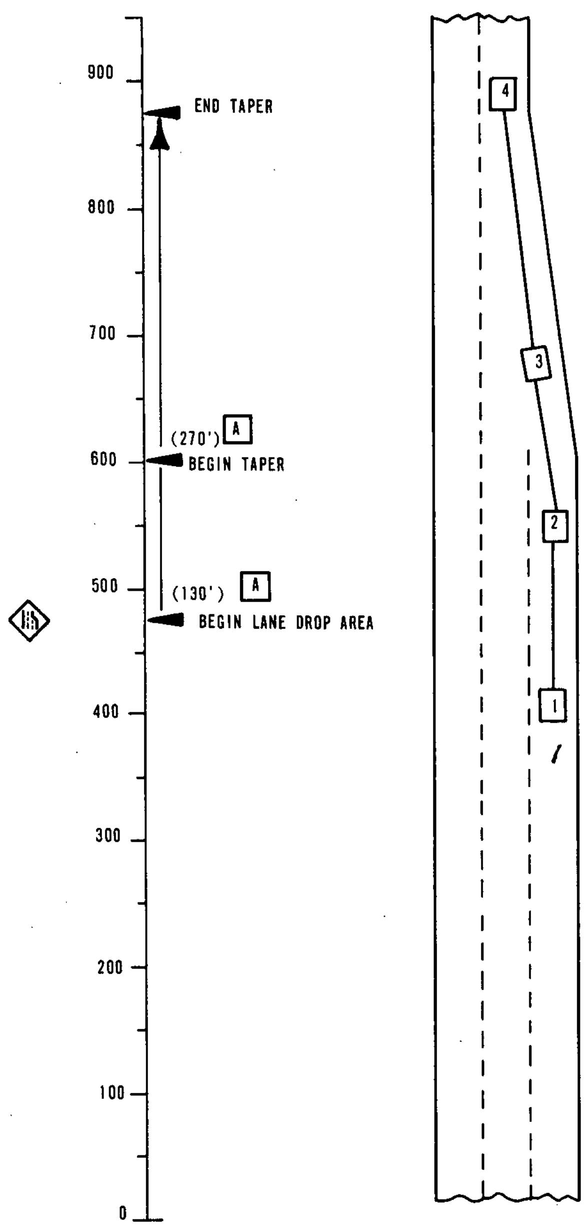

Figure A-11. Maneuver diagram for pavement width transition (lane drop).

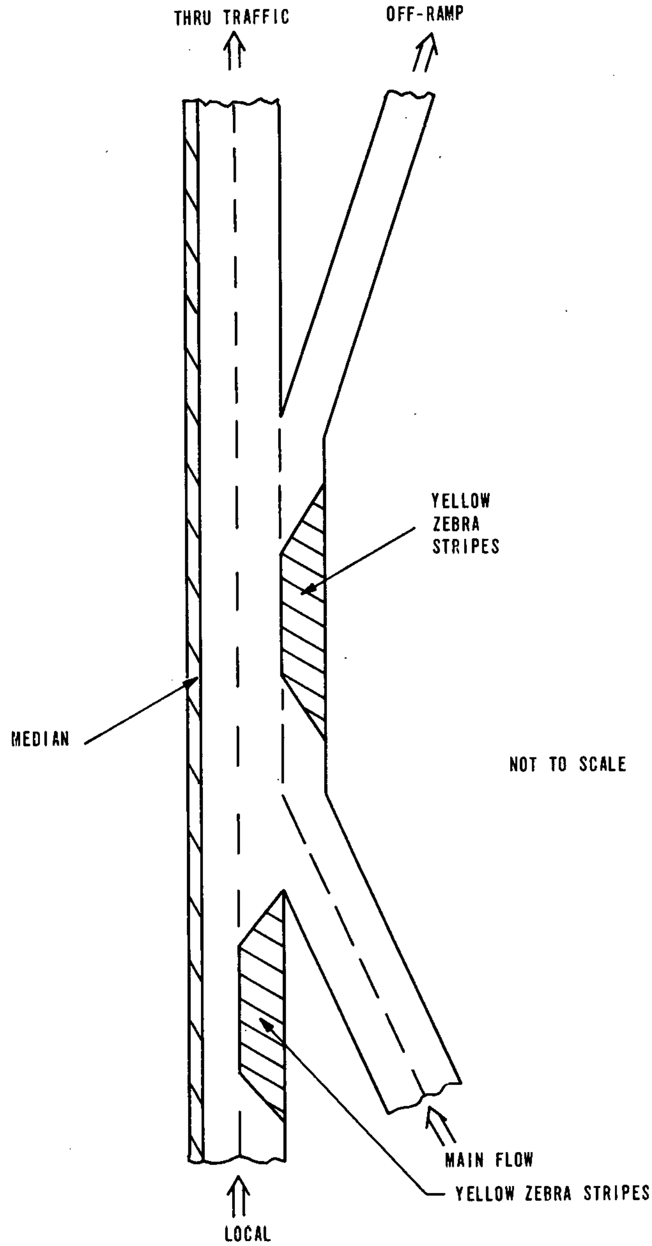

Figure A-13. Painted lane drop, Pennsylvania.

ently, those who approach from the direction labeled "main flow" and desire to get off at the off-ramp pass over the second yellow zebra striped area; in fact, it appears that very few move to the left and then back to the right for the exit maneuver. This, again, illustrates the point that drivers will ignore what they consider to be unnecessary or unreasonable restrictions. (The violation of a yellow zebra strip area is obviously intentional, as the message is clearly understood by all drivers.) Yellow-colored pavement was installed in these areas as part of a study within this project (see Appendix K for details). In general, fewer drivers encroached on the yellow pavement than on the zebra striping. (Pennsylvania, 1969, B)

5. The delineation system employed at the stage construction lane drop shown in Figures A-14 and A-15 is comprised of white edge line (both sides), black or yellow warning sign, and amber post delineators, all of which are visible in varying degrees in both day and night photographs. (Florida, 1969, B)

6. Figure A-16 shows the diagonally striped, black-and-white bridge end panels as applied to part of the taper of a lane drop section in North Carolina. It should be noted that the direction of the diagonal would be reversed if a taper-left drop were delineated. These panels appear to have a daytime delineation advantage over regular post delineators (see Fig. A-14) and are adequate as nighttime delineation. (North Carolina, 1969, B)

Figure A-14. Post delineator treatment at lane drop (day), Florida.

Figure A-15. Post delineator treatment at lane drop (night), Florida.

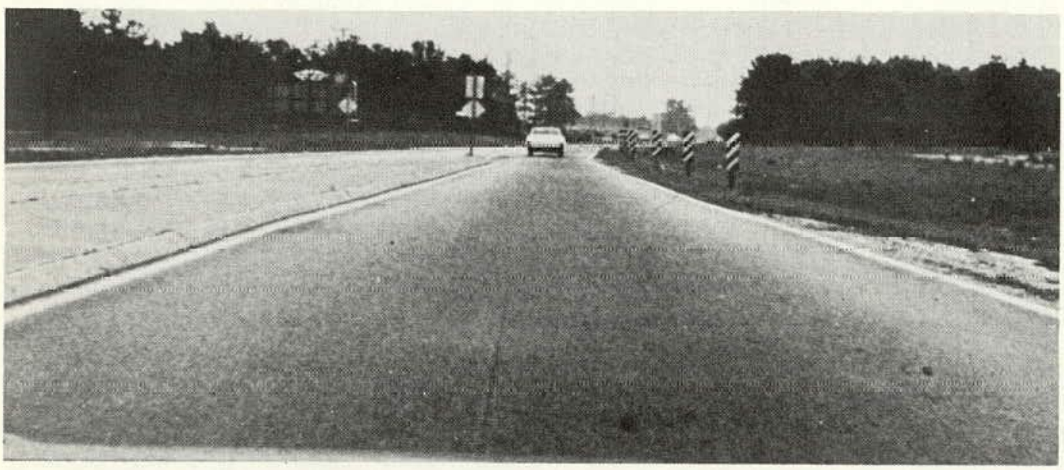

Figure A-16. Bridge end panel treatment at lane drop, North Carolina.

Synthesis and Evaluation

To a large extent, information required by the driver in pavement width transition situations is a function of the reasons that dictate these transitions. Excluded from consideration in this section are pavement width transitions where the pavement widens to produce a flared tangent, as this is a minor problem relative to the narrowing or reduction in the number of travel lanes.

A lane is dropped in the road design stage usually because projections indicate that a high-volume off-ramp will be located upstream of the drop area; thus, the reduction is justified on the basis of reduced demand. At other times, however, the reasons for the reduction are either economic, as typified by stage construction situations, or geometric, covering those cases where topography or existing structures impose limits on the available right-of-way.

Different operating conditions are likely to be observed, depending on the underlying reason for the lane drop. For example, in the case where the roadway width is reduced because of lower volumes expected following an off-ramp, a reduced volume can be expected to offset the reduction in width. However, in the case of stage construction, volume may continue high through and beyond the lane drop area. Hence, disruption in flow is much more likely to result. Finally, geometric constraints, while also usually independent of volume/level-of-service considerations, do differ from stage construction situations in that the conditions are more permanent and the lane drop type selected is less influenced by future construction needs. On facilities where substandard designs exist because of unanticipated or changing traffic patterns, the traffic engineer must resort to control devices such as pavement markings, channelizing islands, and barriers to improve the flow pattern. Often, improvement requires dropping the lane upstream of a hazardous and/or difficult maneuvering area. (An example of this type of situation is shown in Fig. A-13.) In addition to the variety of reasons justifying a lane drop, there is an even greater variety in the configurations of drops employed to satisfy those reasons. To mention a few of the more important parameters: (1) the number of lanes often changes from 4 to 3, 3 to 2, and 2 to 1, etc., and (2) the location of the dropped lane (i.e., a taper on the right, a taper on the left, or pinching out the inner lane).

In treating lane drop situations, traffic engineers have relied heavily on the symbolic cue sign to provide the early warning information that the driver needs. It is interesting to note that the results of an informal survey show that, for the most part, drivers recognize the sign almost immediately and prepare for the impending maneuver. However, this same survey suggests that the presentation time of these signs is generally insufficient to determine which lane is to be dropped.

In lane drop situations where the actual pavement does not narrow, but delineation is used to channel traffic through a critical area (as in Figs. A-12 and A-13), it would seem that the effectiveness of the drop is influenced a great deal by the type of treatment employed. In the example shown in Figure A-13, it would appear that the local drivers have no serious need for information regarding the geometry and distance and time correlations between points. The total informational deficit, then, relates to the finding of a gap in the major flow. A serious inconsistency in the message being conveyed to the driver is typified by this type of situation. Yellow, as a code, conveys basically two messages to the driver:

1. An area of non-encroachment, such as the drop depicted.
2. The message "keep to the right," the standard the revised "Uniform Manual" seems to promulgate, but is here contradicted.

In still another lane-drop-type situation, both messages appear to agree. This is in a case where old-design, three-lane roads are marked intermittently to provide two lanes of travel in one direction and one lane in the other; with the process being reversed downstream to aid flow in the opposing direction. The current practice survey indicated that the treatment to effect this type of drop varies from a single diagonal line to crosshatched areas in the center lane to provide a recovery area for inattentive drivers approaching the drop. In general, the degree of taper provided is consistent with the warrants based on prevailing speeds and appears, in most cases, to be adequate.

Other treatments that appear to be effective in informing the driver of the location of, and demand in the maneuver area involve post delineators with a spacing reduction for the taper area, as in Canada (see Appendix D).

Suggested Research

To date, signs provide the primary cues for the driver to inform him that a pavement width transition is ahead. This should probably continue to be the case. However, the following areas of research show promise of improving the information transmission through delineation:

1. Investigation of various spacings of post delineators to forewarn drivers, particularly in the case where the pavement width narrows, but also in the case where the pavement width widens. A special problem here would be to ensure that the driver does not confuse any recommended pattern, or patterns/color coding with other situations, such as off-ramps or horizontal curves.
2. It may be possible to provide advance information through variations in the lane line between the lanes to be dropped as they approach the merging area. Again, care must be taken that any suggested pattern is not confused with patterns indicating other situations. (A recommended line for this purpose is described in Chapter Four.)
3. In the case of raised pavement markers, the lane line simply will disappear as the two lanes merge. Because raised pavement markers are not used for edge lines, this situation could be particularly confusing to the driver at night, as the reflective markers would be visible for a considerable distance beyond the distance at which the painted edge lines could be seen. Combinations of raised pavement markers and post delineators in various configurations should be studied for this case.
4. Colored pavements have the potential of providing

the driver with a positive and continuous message that "something is different about this lane"—the lane to be dropped. If a readily understood code can be applied, this treatment may be very effective for this situation. (See Appendix K for description of a pilot study in this application of colored pavement.)

MERGING/DIVERGING AREAS

Driver Information Needs

The merging and diverging situations are considered together in this section. However, because the geometric configurations are different, flow charts and maneuver diagrams have been developed for both situations; Figures A-17 and A-18 apply to the merge situation, Figures A-19 and A-20 to the diverge situation.

Merge Area

The example illustrates the merging of four lanes into three. The only signing is an advance warning sign placed 750 ft upstream of the beginning of the merge area, and a merge sign located just ahead of the beginning of the merge area.

Diverge Area

The example illustrates the divergence of two lanes into three lanes of traffic flow. An off-ramp is assumed, into which a deceleration ramp with taper extends. Assuming a highway design speed of 60 mph and an off-ramp design speed of 35 mph, the total length of deceleration lane would be 400 ft.

The lane marking and signing conforms to recommendations in the *Manual on Uniform Traffic Control Devices*, and current practices.

Current Practices and Related Research

1. California conducted a study examining the accident experience on 722 freeway ramps during a three-year period. The study covered 1,643 ramp accidents and showed that the accident rates on the on-ramps were consistently lower than those for the off-ramps. The average on-ramp rate was 0.59 accidents per million

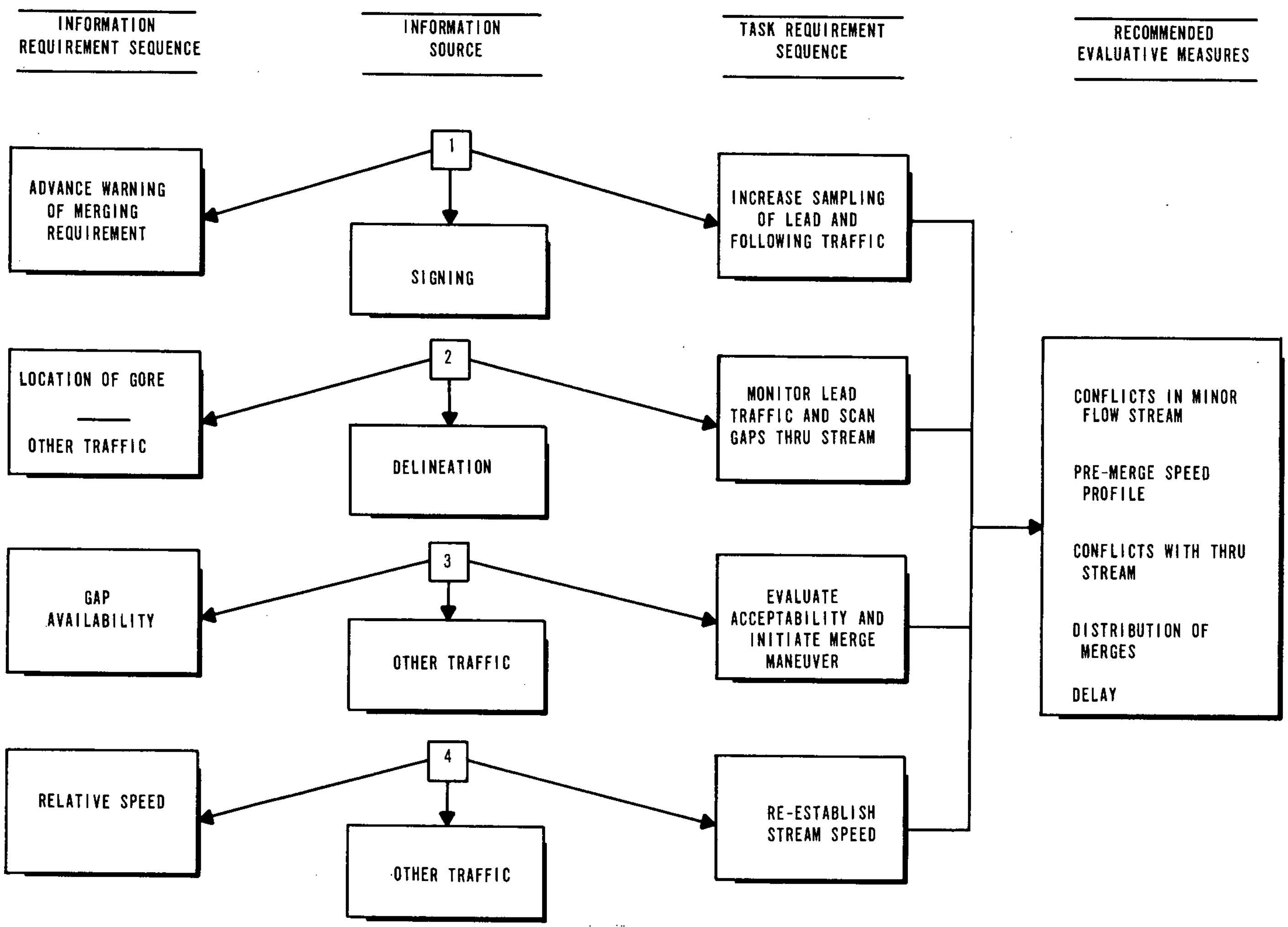

Figure A-17. Flow chart for merging area.

vehicles, whereas the average off-ramp rate was 0.95 accidents per million vehicles. (California, 1965, *31*)

2. The diverging area shown in Figures A-21 and A-22 is an example of a complex delineation system. Not only has extensive use been made of reflectorized paint (lane line, edge line, gore guardrail) and post delineators, but the guide signs and post delineators also are color coded. The left-hand sign is blue; the right is standard Interstate green; the post delineators are blue to the left and amber to the right. Examination of the night view indicates the potential visual clutter problem that may occur with the combination of some alignments and high-reflectivity delineators. (North Carolina, 1969, B)

3. Colorado is tending to phase out the use of diagonal stripes in gore markings. Highway officials there believe that driver performance is not affected by their absence. (Colorado, 1969, B)

4. Arizona is also experimenting with gore markings without the diagonal stripes (see Fig. A-23). They are also experimenting with the use of reflective raised pavement markers without paint stripes (see Fig. A-24). In this latter treatment, they use ceramic raised pavement markers for daytime delineation; the patterns look roughly the same. (Arizona, 1968, B)

5. Texas has used the "blue tunnel" of raised pavement markers in Waco. At this time no definitive study has been made to determine the effect of this treatment on driver performance. (Texas, 1969, B)

6. The "blue tunnel" treatment has been installed at several ramps on the Monterey Freeway in California. In this instance, no post delineators were used in conjunction with the raised pavement markers due to resistance from a citizen's group who complained that post delineators are aesthetically displeasing. (California, 1969, B)

7. Chaney, California Division of Highways, reports that the raised pavement markers provide a significant advantage over post delineators when the curvature is tight as they are not superimposed on one another and so define the pathway with greater clarity. On the other hand, they are visible for relatively shorter distances on vertical curves and so supplemental marking is often required. (California, 1968, C)

8. Visual observation indicates that amber pavement markers on the outside of ramps, with blue on the inside, do not provide any better delineation than blue on both sides, and the latter treatment is aesthetically superior. (California, 1969, B)

9. Arkansas has experimented with the use of precast plastic buttons to mark on- and off-ramps on I-30 in Little Rock. The study was materials oriented and no findings are presented indicating the effect of buttons on traffic behavior. (Arkansas, 1965, *88*)

10. Rumble strips have been used on some ramps in California. The cost is high, and the subjective opinion of the Delineation Task Force is that they are not worth the cost. (California, 1969, D)

11. Guardrails sometimes provide more effective delineation than post delineators or raised pavement markers. It has been suggested that break-away guardrails be used as a delineation treatment for hook ramps. The theory is that if one leaves the road, less damage will result from going through the guardrail than from being stopped by a standard guardrail. (California, 1969, B)

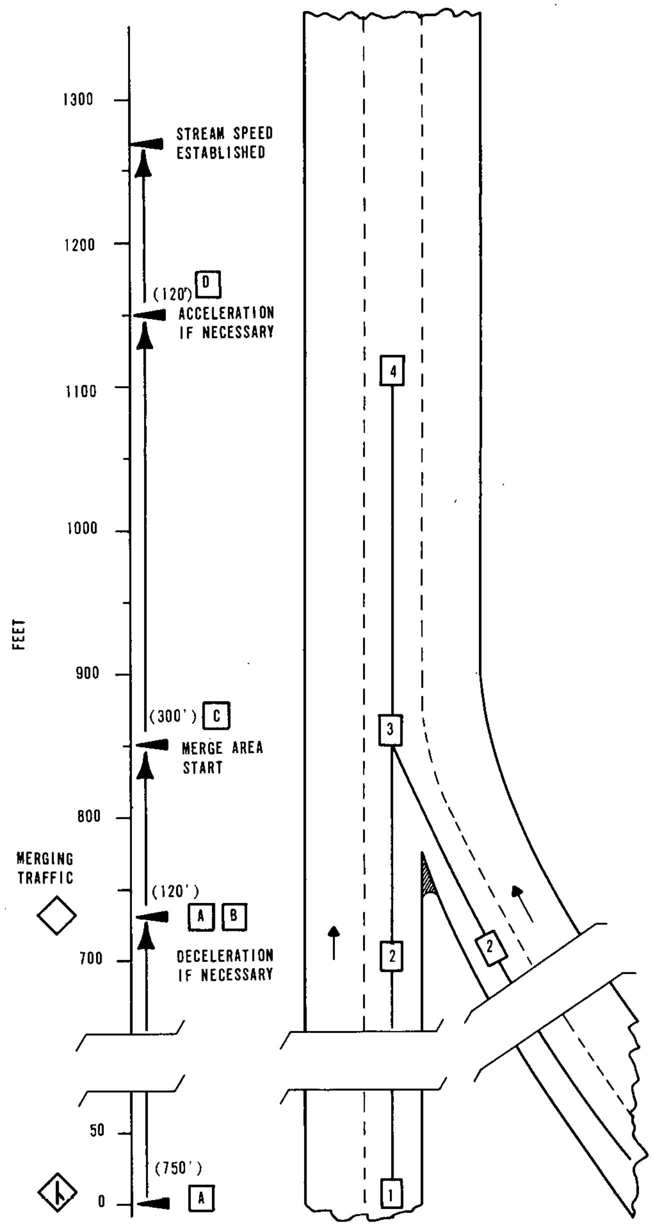

Figure A-18. Maneuver diagram for merging area.

The systems approach to delineation has had more application in the merge/diverge situations (particularly freeway ramps) than in any other of the common delineation situations. The following items report on studies related to the use of these systems:

1. Minnesota used triple blue delineators, full-width blue reflectorized pavement paint, and blue exit signs to delineate an exit ramp (the directional signs remained green, however), varying the degree of delineation and lighting in five different combinations. From driver inter-

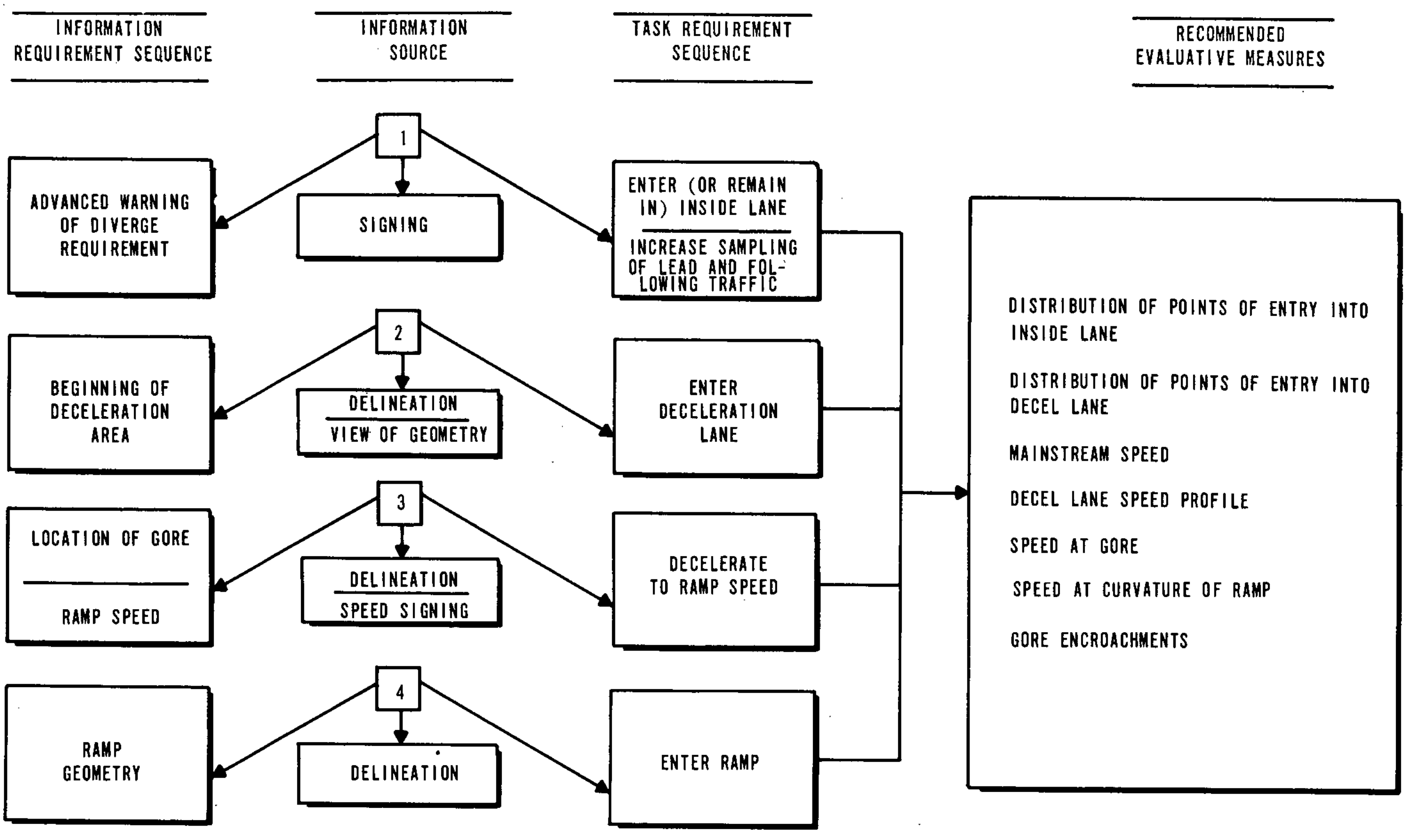

Figure A-19. Flow chart for diverging area.

views it was found that lighting is the most important factor for reducing driver confusion and error, but that the delineation was also helpful. Under standard delineation, route markings seemed most important for information on where to turn; with the new delineation, the reflectors and pavement paint took on the major responsibility for guidance. (Minnesota, 1960, *26*)

2. In a follow-up study to the previous one, the following changes were made: the full-width pavement paint was changed to 12-in. edge lines because drivers had slowed down unnecessarily at the abrupt end of the paint; the yellow and blue colors were intermixed on various exits and entrances to determine whether any effects were due to a particular color or the introduction of color per se. Otherwise, the treatment was the same as before. The BPR Traffic Analyzer was used to record speed, placement, volume, and vehicle classification data. Erratic maneuvers were recorded manually. Analysis of the data indicated that vehicles had higher speeds and exited later at the blue exits during the daytime. No other valid conclusions could be drawn from the data. The majority of drivers interviewed (75 percent) had not noticed the color treatment at all; but those who had believed it was beneficial, especially at night. Particular colors were responsible for particular reactions (yellow had a definite cautionary effect). (Minnesota, 1963, *1*)

3. Michigan color coded a 30-mile section having 18 interchanges. Exit ramps had 8-in. blue edge lines and blue post delineators. Blue backgrounds were used for exit and destination signs. This system resulted in reduced erratic movements. (Michigan, 1967, *3*)

4. Michigan also conducted a study involving two interchanges having two-lane left-hand exits. The system consisted of 8-in. blue reflectorized edge lines, 4 × 10-in. blue rectangular delineators, with blue exit and directional signs. The system significantly reduced erratic maneuvers. In addition, 85 to 90 percent of the drivers interviewed believed that the system was beneficial. (Michigan, 1966, *91*)

5. In Connecticut, exit ramps were delineated with 4-in. edge lines (white on the left and yellow on the right) and dual 3-in. amber reflectors on both sides under varied illumination. Speeds, lateral placements, headways, and vehicle entrance points on the deceleration lane were recorded. The major difference was that with this treatment night use of the off-ramp more nearly approached daytime use in terms of the length of ramp used. Neither speeds nor placement nor headways were affected consistently. (Connecticut, 1960, *55*)

6. Ohio conducted an experiment in color coding that used blue delineators, blue edge lines, and blue guide signs at an exit ramp and yellow delineators and edge lines at an entrance ramp. The system was in use for two years, after which driver interviews were conducted—91 percent of the drivers responding had noticed the color system and 86 percent understood its meaning. (Ohio, 1965, *38*)

7. Oregon used 8-in. blue edge stripes and triple blue

reflectors on five exit ramps. The gore markings were half white/half blue, and the exit signs were changed to blue. Color coding had no effect on speeds or accidents, but did appear to result in a smoother path for exiting vehicles. (Oregon, 1966, *11*)

Synthesis and Evaluation

When the labels "merge" and "diverge" are affixed to a traffic maneuver, they are usually associated with entrance and exit ramps on freeways. Although this project was primarily concerned with non-ramp merge and diverge operations, most of the studies involving these operations have been directed to ramps. Because treatments developed for exit/entrance situations find application for non-ramp geometries, ramp studies are included here.

The model combination procedure suggested in Appendix B applies here; that is, models developed for the merge and diverge areas can be combined to produce a more complex model—the weaving section. To depict the ramp merge situation, the pavement width transition model could be applied to the merge model. In these combinations of models the informational components are of the same type, but the severity of the demand placed on the driver in the more complex situation may be more than the simple sum of the demands of the individual maneuvers, because requirements at times overlap, depending on the particular geometric configuration. For example, the driver may be required to anticipate the diverging maneuver before completing a merging maneuver, when, for example, he must follow a junction to the left immediately after entering a freeway from the right. Although situations of this type do not generally occur on rural highways, the problem does occur on urban freeways where distances between ramps serving arterial streets are often short.

Of the possible configurations to be discussed in this section, perhaps the most elemental and least demanding maneuver is a non-ramp diverge. The basic task involved is tracking while leaving a common stream. Generally, the tracking task is simplified because changes in velocity are seldom required; thus, the driver need concern himself solely with lateral placement. In the simplest form of the non-ramp diverge situation, the only advance information required by the driver is location of the gore. Complications in the non-ramp diverge situation increase as the number of lanes upstream of the diverge point increases. This greater measure of complexity comes about because more drivers must make lane-changing maneuvers.

Increased lane changing may also contribute to the relatively high accident experience in the ramp diverge maneuvers, because a high percentage of drivers either cross one or more lanes to effect entry into the deceleration lane, or, less frequently, fail to effect entry early enough. In the latter case, considerable hazard results in the form of high-speed rear-end collisions, because the exiting driver generally resorts to severe adjustive maneuvers to gain the deceleration lane prior to the gore.

There is reliable evidence that the accident experience at off-ramps is generally greater than at entrance ramps. In one sense this is surprising, as the basic diverging maneuver is considerably less complex than the merging

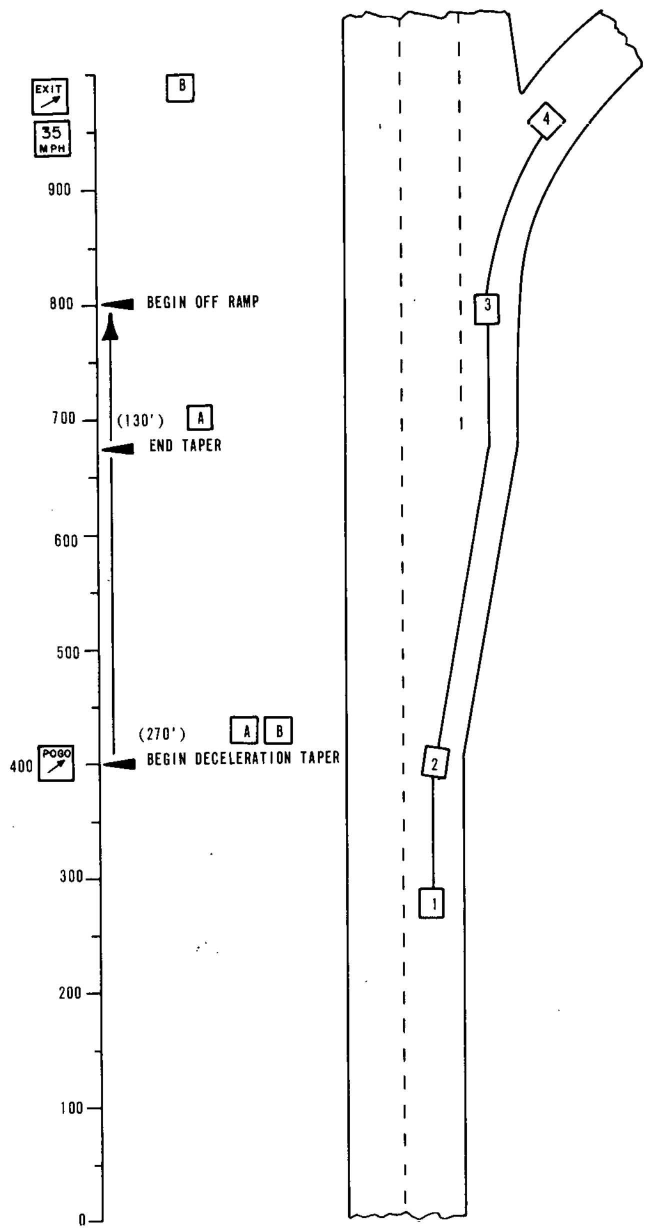

Figure A-20. Maneuver diagram for diverging area.

maneuver, in that the latter requires the driver to factor into his gap evaluation process such things as time headways, acceleration potential, closing rates, relative speeds, the distances between his vehicle and those defining the gaps, and the end of the acceleration lane. In still another sense, the relative accident incidence between the on-ramp and off-ramp situation can perhaps be accounted for because the on-ramp driver, despite the difficulty of the decision process, is aware that he is involved in a critical situation. The exiting driver, on the other hand, is traveling at a high rate of speed and may have adapted to a "no change" situation.

Mace, et al. (*140*), demonstrated that the placement of advance warning information is important in effecting ap-

Figure A-21. Diverge area (day), North Carolina.

Figure A-22. Diverge area (night), North Carolina.

propriate exit maneuvers. Their results indicate that if given too much advance warning the driver tends to pass if impeded; hence, he finds himself out of position to effect early entry into the deceleration lane. Information presented in advance but close to the beginning of the deceleration lane generally results in an erratic maneuver; i.e., the hazardous late entry just prior to the gore that was previously discussed. Optimum placement of warning information seems to change the distribution of lane-changing maneuvers such that the driver can assume the proper lane position upstream of the beginning of the deceleration lane, but not so far upstream that he will be tempted to pass another vehicle before entering the deceleration ramp.

Ramp situations, in general, seem to have received more "systems" attention from traffic engineers than any other situation. Again, the problem of consistency in delineation treatment arises. Project personnel tend to agree with Hulbert (*137*) that the concept of uniformity should apply to basic principles and that unique warning systems should be designed for unique situations. In the off-ramp situation, however, one finds two "systems" competing as a standard. Until a few years ago, common practice for treating exit areas amounted to standard white edge lining, standard gore marking, and changing the clear post delineators to amber in the vicinity of the deceleration lane and ramp. In recent years, several traffic engineers have used blue delineators and edge line to code the exit situation. In California, Texas, Michigan, Minnesota, Ohio, and Oregon, experimental blue exit systems have been installed. In the states testing the so-called "blue tunnel" delineation

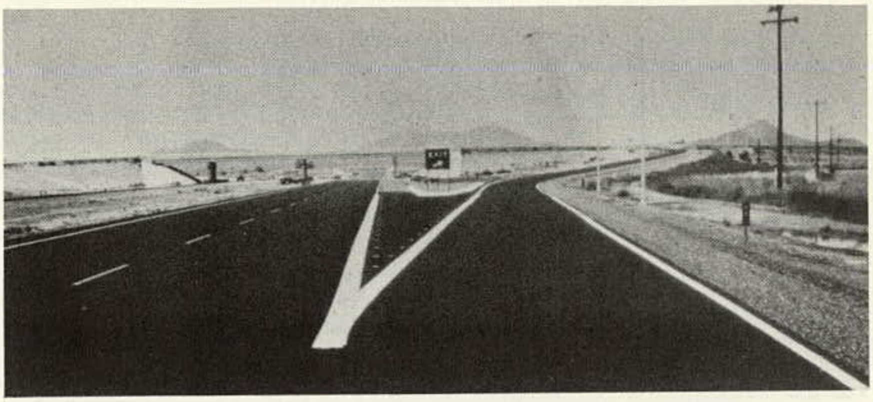

Figure A-23. Paint stripe gore treatment (no diagonal marking), Arizona.

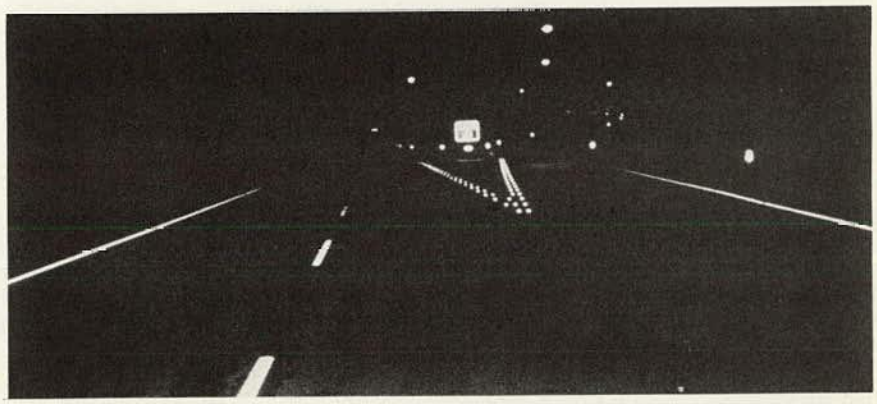

Figure A-24. Raised pavement marker gore treatment, Arizona.

system, exit delineation systems where the principle code is yellow or amber have also been installed. It would seem, from the results of these studies, that the value of color as a concept or as a code (i.e., whether effectiveness is due to a change in color per se or use of a specific color for a specific situation) has not yet been resolved.

Again, striving for uniformity in basic principles and recalling the admonitions of the MUTCD pertaining to the use of yellow (i.e., it should be restricted to the message, "keep to the right"), the use of a blue exit code would seem to be desirable. It would further seem that the blue code would be more effective if it were restricted to the exit situation. Field observations of yellow post delineators, for example, indicated that although they were detectable on tangent sections far upstream of the interchange and were interpreted by the driver as ramps, no decision could be rendered as to whether they were exit ramps or entrance ramps until the driver had received additional cues in his approach.

Interestingly enough, the confusion between ramp type occurs where alignment is of high quality. In these cases, ramps are often at or near freeway grade, so that the height of the reflectors is relatively uniform, thus depriving the driver of pattern cues that might be apparent if the ramp was changing in grade. Often, where exit and entrance ramps are adjacent the reflective delineators blend to form a single-line pattern.

For the merging driver, delineation treatments serve principally to define the physical limits of the ramp and acceleration lane area. With respect to the acceleration lane per se, the model for pavement width transition applies directly; that is, the critical informational need of the driver is the available distance. An additional component in the entrance ramp situation, however, is the ramp nose, or the end of the physical barrier that prevents merging attempts while the angle of the merging driver is still relatively acute. Again, it should be emphasized that in a merging situation, the more critical information is that associated with the relative vehicle dynamics. Thus, truly effective ramp delineation is that which detracts least from the driver's search for an acceptable gap. The effective delineation treatment would also indicate to the mainstream driver that he is approaching a merging area so that, traffic permitting, he could move to the left to provide access to the entering vehicle and at the same time minimize disruptions in flow.

A variation on the use of the color concept or color code on ramps is found in the form of pigmented pavements. However, the color-effectiveness is poor at night. During the day (when the need for delineation is not so great) travel paths of colored pavement seem to be reasonably effective. It should be noted that the blue RPM's and post delineators employed in the blue tunnel installations are relatively poor for daytime delineation. If cost were not a serious problem, the combined attributes of these treatments in providing individually for nighttime and daytime delineation would argue for a system that employs color coded treatments, including colored pavement, reflective raised pavement markers or edge striping, and the blue reflective post delineators.

Suggested Research

Although the scope of this project specifically excluded freeway ramps, it is not possible to exclude consideration of the delineation treatments used in those situations. Many of the concepts and treatments developed in ramp studies apply to other merging/diverging areas. Equally important, it is essential that the treatments be sufficiently different in application so that drivers will not be confused. Hence, research could profitably be directed toward the following areas:

1. Investigation of the possibility of applying the results of research studies on ramps to the non-ramp merge/diverge situation.
2. Investigation of color coding in merge/diverge situations. Determination of whether a change in color or the use of a specific color for a specific delineation situation is effective in conveying the message to the driver. Again, care must be taken to assure that color coded treatments will not contribute to confusion between ramp and non-ramp situations.
3. The merge/diverge situation is also similar, in many respects, to the pavement width transition situation. Therefore, research similar to that suggested at the end of that section could be profitable in a wider context.

In summary, research directed toward the application of concepts and/or treatments to entrance and exit ramps, non-ramp merges and diverges, and pavement width transitions must be cognizant of the similarity of the situations and assure that recommendations do not further confusion. In a sense, then, it is not possible to direct research toward one of these situations without consideration of the other two.

TURNS

Driver Information Needs

A review of the literature showed that little has been reported regarding current practices or related research for the delineation of simple turns. Consequently, although flow charts and maneuver diagrams for simple turns and turns with deceleration/storage lanes have been developed and are presented as Figures A-25, A-26, A-27, and A-28, both turns are discussed in this single section.

Turn (Simple Geometry)

The illustration of a simple turn maneuver is similar to that of the stop approach, except for the turning path. The calculated distances for maneuvers must of necessity be based on the possibility of a complete stop. The turning path will, of course, vary, depending on whether a right or left turn is being made. The example shows a left-turn path. A route junction and route marker sign is used for advance warning of the intersection. The possibility of performing a lane change is incorporated into the maneuver because sufficient distance is contained in the deceleration-coasting phase to consider this. A route verification sign is shown on the cross road after the turn is completed. Included also is a destination sign 200 ft in advance of the cross road.

Turn (with Deceleration/Storage Lane)

The total distance covered by the necessary maneuvers in this example is 900 ft, as indicated in Figure A-26. This is considered from the start of the delay associated with the search for an acceptable gap in the adjacent lane to the stop line. A cross road sign is used to show the presence of a cross road, and a LEFT TURN ONLY sign is used to indicate the turning maneuver. Other information is provided by the delineation markings, signal, and stop line.

The total distance consists of lane change delay search, lane change maneuvering, and comfortable braking distance. These distances vary as a function of vehicle velocity.

Current Practices and Related Research

1. California's "Evaluation of Minor Improvements" study was designed to develop objective criteria for the evaluation of minor improvements and thereby permit maximum safety benefits per dollar spent in the minor improvement program. The study reports the following results:

(a) Painted intersections appear to reduce accidents as much as, if not more than, physically protected intersections on highways where the zoned speed is 55 mph or greater. Thus, painted channelization should be considered in these situations.

(b) An accident rate reduction of 50 percent was reported for the 40 intersections where left-turn channelization was installed. (At 19 of these sites, where the recommended warrants were met in full, a 60 percent accident rate reduction was noted.)

(c) Assuming a ten-year life of project, the average cost per accident reduced by left-turn channelization is \$250. These costs were \$314 for the unsignalized intersections and \$59 for signalized intersections. (California, 1968, *28*)

2. In another California study, the traffic accident experience on a 1.14-mile section of highway was compared before and after paint channelization of the section. There were significant reductions in rear-end and left-turn accidents. (California, 1968, *39*)

3. A California study shows that painted left-turn chan-

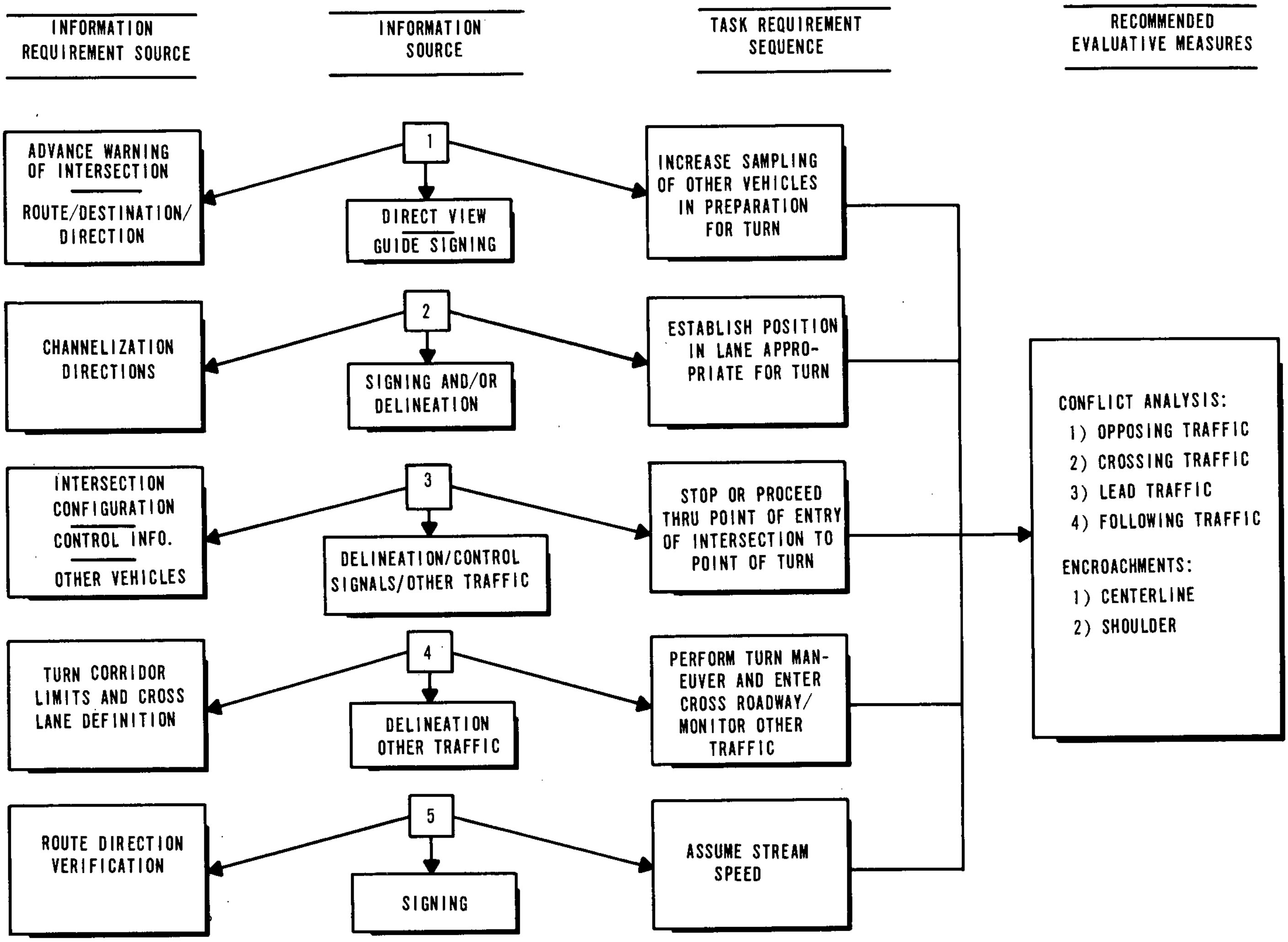

Figure A-25. Flow chart for turn (simple geometry).

nelization was more effective in rural areas than in urban areas. (California, 1968, *28*)

4. Texas has used continuous left-turn lanes successfully in strip development in suburban areas. These left-turn slots are 12 to 16 ft wide, outlined with solid white lines on both sides, and are usually pavement lettered LEFT TURN ONLY. (Texas, 1969, B)

5. Figure A-29 shows the delineation treatment at a left-turn slot in North Carolina. Note that the left-turn lane also permits a through vehicle maneuver; the dashed line (1-ft mark to 15-ft gap) crossing the intersection acts to channelize through traffic back into a single lane. (North Carolina, 1969 B)

6. High turning volumes at the T-intersection shown in Figure A-30 are responsible for the unusual paint marking system employed. Right-turn movements and through traffic are channelized by a median crosshatched area. Through traffic, after squeezing right, is directed via arrows to use the outside lane for through or right-turn movements downstream of the T. Curved arrows are used in the center lane of the three-lane section to direct the crossing left-turn traffic. Note also the lack of edge line from the beginning of the pavement flair to the intersection, an area of apparently soft shoulder. (North Carolina, 1969, B)

7. Montana permits the use of dotted lines to continue longitudinal lines on the through lane through difficult intersections. These are 2-ft marks with 6- to 12-ft gaps. (Montana, 1969, B)

8. In some instances, Colorado carries the line defining the right edge of the left-turn slot through the intersection —producing a buttonhook pattern. (Colorado, 1969, B)

9. In 1962 a study was undertaken in Ohio to evaluate the use of colored pavement as a control and guidance device through intersections with left-turn slots. The turn slots were paved green, whereas the median areas preceding them were paved yellow. The evaluation included an analysis of changes in approach speeds, traffic flow patterns, and lane position. Their findings were:

(a) Introduction of colored pavement at an intersection does not significantly affect the velocity of vehicles in the through lane.

(b) It appears that application of the colored pavement is effective in channelizing the left-turning vehicles entering the turning lane. This is accomplished primarily by directing the vehicles around the island area rather than by inducing the drivers to enter the left-turn lane earlier.

(c) Use of the green pavement in the turning lane apparently did not affect the drivers' patterns of entry into the lane.

(d) The colored pavement had little effect on traffic flow patterns at night. (Ohio, 1962, *16*)

Synthesis and Evaluation

In general, intersections (or access points) with a deceleration and/or storage lane impose nearly identical task requirements on the driver as in the diverging maneuver. At some point just prior to arrival at the end of the deceleration lane, however, the turning driver is required to evaluate control signals and adjust his speed and position accordingly.

In urban areas, the majority of turn slots occurring at intersections (as opposed to access points) are controlled. Hence, the driver's decision alternatives are fewer and less confusing; i.e., when the driver receives the signal to proceed through the intersection, opposing traffic is controlled by the stop light. Rural slots differ in that more of the uncontrolled variety occur and, in general, the storage lane must also function as a deceleration area to accommodate the higher speeds found in the rural situation. In the process of adjusting his tracking behavior the driver must also process traffic in the opposing direction and, not

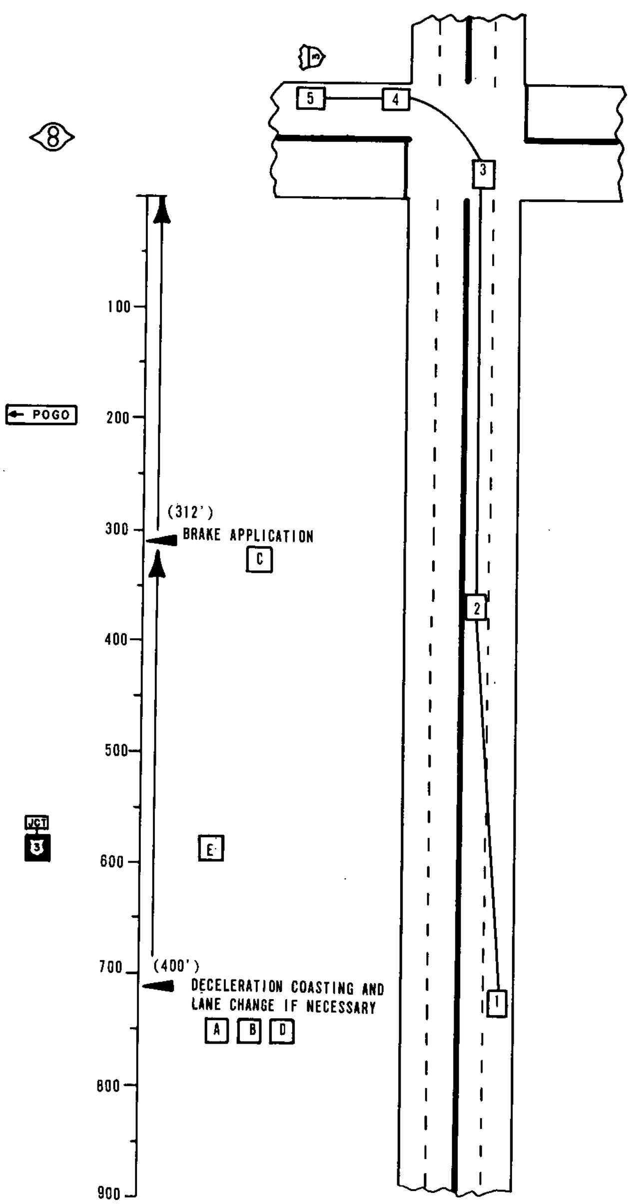

Figure A-26. Maneuver diagram for turn (simple geometry).

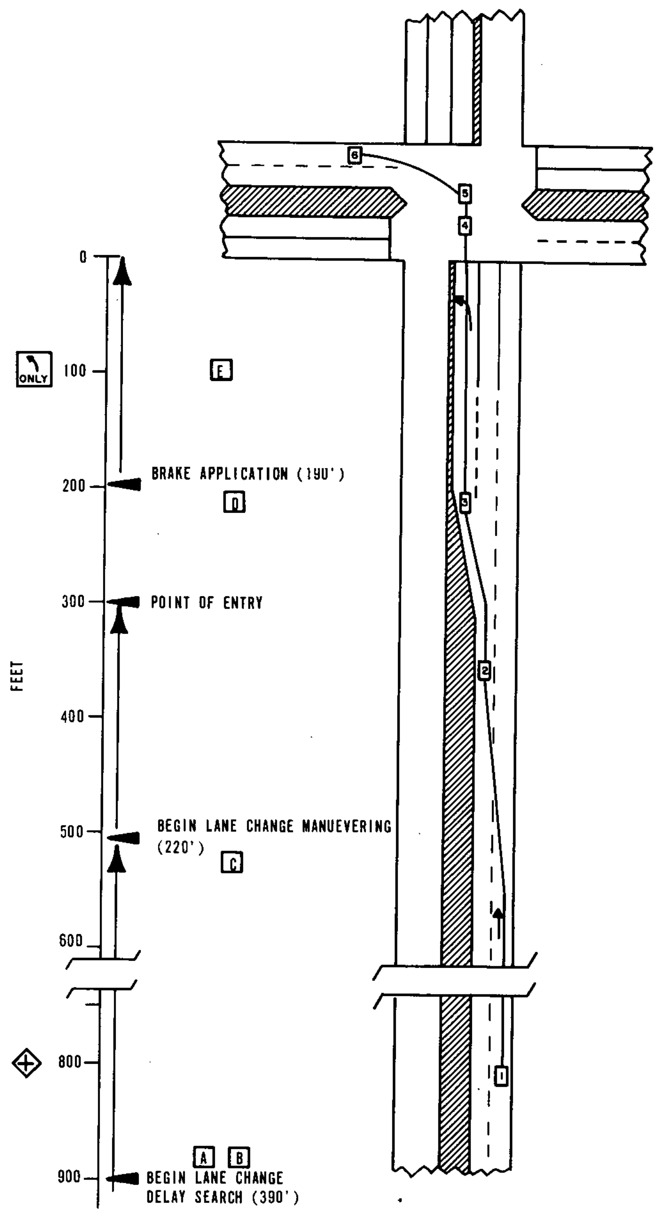

Figure A-28. Maneuver diagram for turn (with deceleration/storage lane).

infrequently, he must search two or more lanes and evaluate the acceptability of gaps in all of them.

As in the diverge maneuver, perhaps the most critical information input is the advance warning that alerts the driver and permits him to position his vehicle such that entry into the turn slot can be effected at the earliest possible time. Once the driver has assumed his position in the lane adjacent to the slot, the most critical information elements become the physical boundaries of the storage lane proper, and whether the available deceleration area is shortened through the presence of other vehicles stored in the turn lane. At this point, the delineation treatment, whatever it may be, serves to provide the driver with a lateral placement reference. More importantly, however, this same treatment (e.g., a solid or broken lane line, raised bars, reflective pavement markers, colored pavements, channelizing islands) provides path information to the through driver to minimize undesirable encroachments in the turn lane.

In urban areas where daytime volumes are high, most treatments that define the turn and through paths to the drivers become ineffective. Drivers tend to maintain very short headways and concentrate on tracking the vehicle ahead as a reference rather than allotting sufficient time to the information search portion of their task. Under the reduced volume conditions generally encountered at night, the effectiveness of delineation treatments may be limited by the degree of reflectivity available.

The turning movement is often confusing for the driver as he moves into the cross road. A recent safety conference in a northeastern state generated considerable disagreement among state police, safety officials, and traffic operations experts as to the proper lane that the driver should enter when turning onto multilane cross roads. The majority felt that the ideal path would carry the vehicle into the medial lane, but a strong minority felt that such an action on the part of the turning driver constituted a violation with respect to the advisory signs that say KEEP TO THE RIGHT, PASS LEFT ONLY.

A related ambiguous factor in the turning movement is a lack of definition of the ideal path relative to the center of the intersection. Should the turning driver pass to the right of the center of the intersection? (In this case two drivers in opposing lanes on the same road, wishing to make left turns onto the cross road, would pass each other such that the left side of each vehicle is closest to the

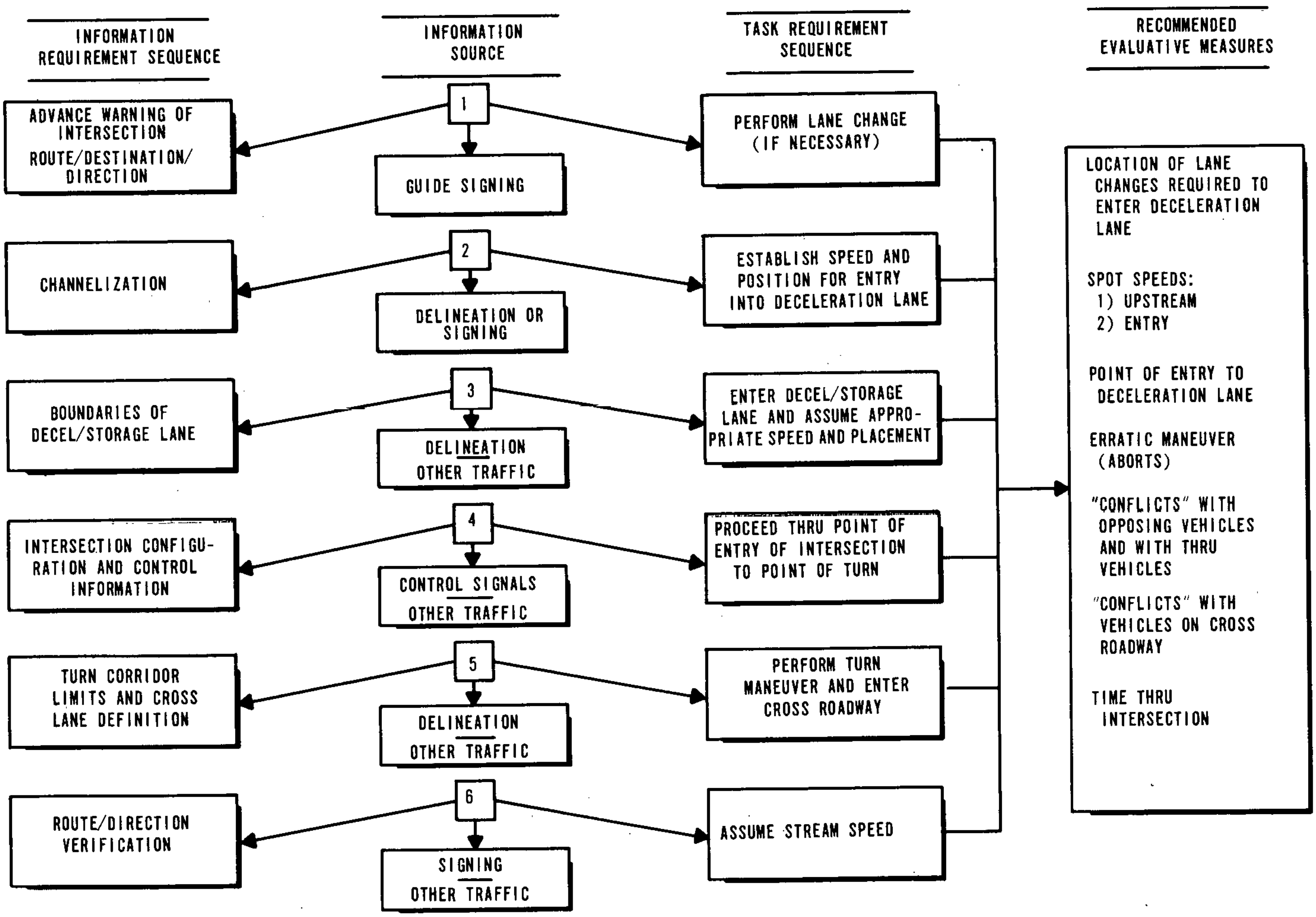

Figure A-27. Flow chart for turn (with deceleration/storage lane).

Figure A-29. Turn-storage lanes, North Carolina.

Figure A-30. Use of pavement arrows at turn locations, North Carolina.

other vehicle.) Or should he pass to the left of center? It would seem that the latter path would be safer and more efficient.

Suggested Research

There is little information that can be provided to the driver through delineation in the simple turn situation. Coding of the pattern of the center line is generally provided, and consideration could be given to coding other lane lines and edge lines. However, in the case of turning maneuvers that involve deceleration/storage lanes, the following areas of research are suggested:

1. Investigation of the use of pavement arrows and their placement; i.e., in the through lanes before the deceleration lane, or just in the deceleration lane.
2. The desirability of using pavement wordings, and their placement, in complex turning situations.
3. Investigation of the desirability of carrying longitudinal lines on the through road through the intersection, possibly with variation in the standard pattern (e.g., the use of dotted edge lines across the minor roads).
4. Investigation of the feasibility and desirability of using more intra-intersection markings to define the turning paths.

RAILROAD CROSSINGS, CROSSWALKS, ETC.

Because of the recent intensive study entitled "Factors Influencing Safety at Highway-Rail Grade Crossings" (*NCHRP Report 50*), no attempt has been made to provide full model development of this "classical" situation. This effort included a model of the driving process composed of the events, observations, decisions, and actions involved. In addition, the report provides an investigation of human factors research that resulted in the definition of general principles to be applied to the design of warning devices and/or systems. Also included was an evaluation of treatments peculiar to the railroad grade crossing, such as crossbucks, wigwags, and flashing light signals. Recommendations are given for the use of the more universally applied delineation treatments, such as rumble strips and pavement markings. A suggestion of considerable merit was that the standard treatments might be installed in such a way as to alter the driver's perception of the situation. For example, to cause him ". . . to slow down through such tricks as converging longitudinal paint lines, or transverse lines with progressively decreased spacing on the pavement."

The perceptual modification technique was employed in a Contra Costa, Calif., experiment that manipulated both length of the rumble strip and the distance between strips on the stop approach such that the vibrational cues remained constant if the driver decelerated in the desired manner.

Richards, et al., recently described the diagnostic study technique employed by the Texas Highway Department as it applies in the medical profession and related the applicability of this approach to rail-highway grade crossing safety evaluation. The team observed numerous unsafe conditions and reported them in order of their frequency of mention. The report indicates that the condition of "pavement markings missing, improperly located, or in need of maintenance" was observed at 72 percent of the crossings. (Texas, 1969, *33*)

As the study reported in *NCHRP Report 50,* previously mentioned, is fairly recent, no suggested research beyond that recommended in that report is provided here.

STOP APPROACHES

Driver Information Needs

The flow chart and maneuver diagram for the stop approach situation are shown in Figures A-31 and A-32. The example shows a stop approach situation where a STOP AHEAD warning sign is not warranted. A CROSS ROAD sign is used to show the presence of the cross road. All other information is provided by the STOP sign and/or stop line.

The total deceleration distance involves two components:

1. In-gear coasting.
2. Comfortable deceleration to a complete stop.

These distances vary as a function of stream velocity. The total deceleration distance in the example is 712 ft. This is calculated using a stream speed of 55 mph. Place-

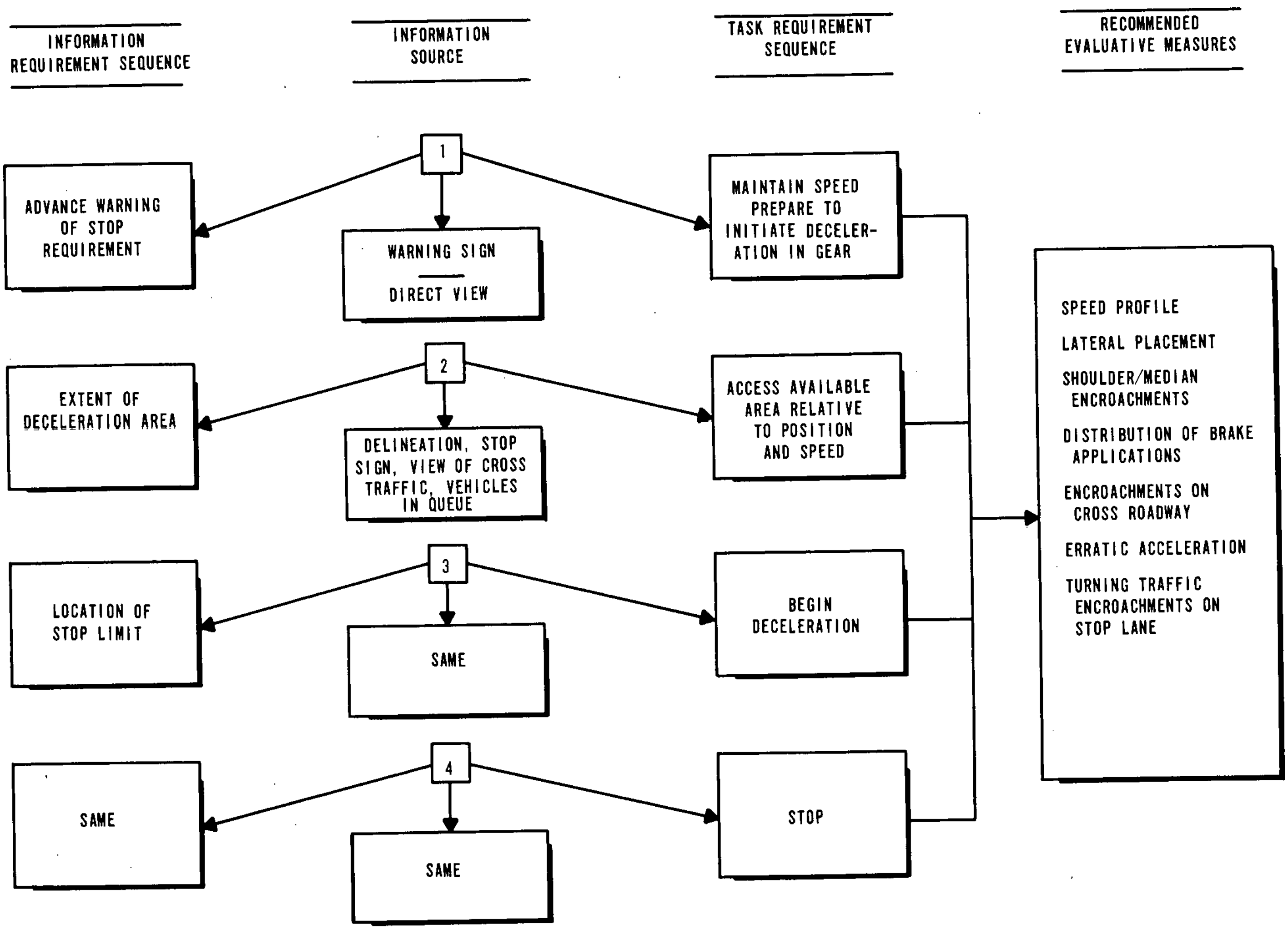

Figure A-31. Flow chart for stop approach.

ment of the CROSS ROAD sign was 125 ft from the start of the deceleration maneuver.

Current Practices and Related Research

1. Kermit and Hein report that the following four distracting phenomena may cause a driver to divert his attention from the primary task of driving, thereby causing him to make various mistakes:

(a) Where there are other distractions competing for his attention.

(b) Where he may become bored, fatigued, or drowsy from driving on long monotonous stretches of rural road.

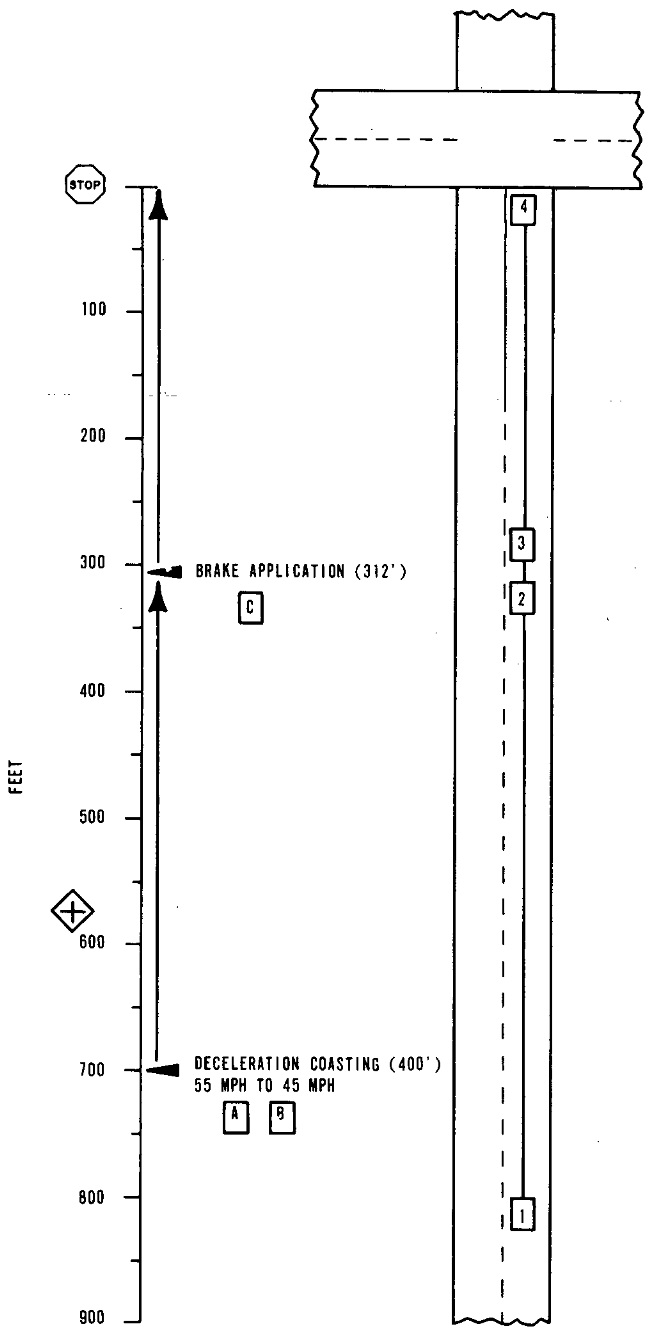

Figure A-32. Maneuver diagram for stop approach.

(c) Where he is preconditioned to easy, rural driving conditions, then suddenly enters an urban community.

(d) Where his experience may lead him to ignore information or warnings because he feels capable of judging the situation himself. (California, 1962, *52*)

2. Owens restates these four accident-causing phenomena in his work. He then states that they "are undoubtedly responsible, either singly or collectively, for most accidents at rural stop locations."

In reporting his study of the effect of rumble strips at nine stop locations in Minnesota, he states that rumble strips utilize the driver's visual, auditory, and tactile senses simultaneously to obtain the desired reaction and warn him of the approaching intersection. His study concluded that:

(a) Rumble strips significantly reduce the speed of traffic approaching rural stop locations.

(b) The number of STOP sign violations was materially reduced as a result of installation of rumble strips.

(c) Rumble strips apparently do not affect all motorists uniformly.

(d) No significant difference was found in the number of center line encroachments by traffic approaching the intersection after installation of rumble strips.

Owens also found that average vehicular speed was lower at a point 500 ft before the beginning of the rumble strips during the "after" study. (The rumble strips were easily visible at this point.) (Minnesota, 1964, *12*)

3. To evaluate the potential of colored pavements as an aid to driver performance and safety, New Jersey installed a section of red-colored pavement to be used in conjunction with STOP signs. Approach speeds, disregard for the STOP signs, and acceptance of lags were the variables measured before and after the installation of the red pavement. Even though the results showed little change in the parameters studied, the authors believed that colored pavement had the potential to convey messages. Two major categories—namely, (1) the materials evaluation and (2) the accident analysis—are still being evaluated. (New Jersey, 1968, *5*) (A similar study was conducted within this project. See Appendix K for details and results.)

4. Rumble strips are effective in reducing accidents at low-volume rural intersections, especially where the intersection is not clearly visible and where accidents involving running of the STOP sign are prevalent. (Jorgensen, 1966, *348*)

5. In July 1960 the Contra Costa County Public Works Department, in conjunction with the California Research Corporation, constructed a series of rumble strips at the T-intersection of Third Street and Parr Boulevard in North Richmond. During the 32-month period (Jan. 1958 to Aug. 1960) preceding the installation, there were 15 accidents at this location; 13 of these were of the overrun type. During the 39 months (Aug. 1960 to Dec. 1963) immediately following the installation, eight accidents occurred. Five of these accidents were of the overrun type. Only two accidents occurred during the next 18 months

(Jan. 1964 to June 1965). Neither of these accidents was of the overrun type. In June 1965 the road was repaved and the rumble strips were not reinstalled. During the next 25-month period (June 1965 to July 1967) six accidents occurred. All of these accidents were of the overrun type. On this basis, Kermit believes that the efficiency of rumble strips has been reaffirmed. In these experiments the strips were spaced so that the vibration remained constant as the driver slowed down. If the driver failed to decrease his speed, the vibration increased, thereby transmitting a sense of urgency. The different vibrations were obtained by varying the lengths of the strips and the distances between the strips. The strips become progressively wider as one approaches the STOP sign, while the distance between the individual strips decreases. Kermit believes that this pattern is an essential part of the rumble strip treatment and is a significant factor in their effectiveness. (California, 1967, *7*)

6. In an earlier report, Kermit (and Hein) indicated that after the rumble strips were installed deceleration took place over a greater distance and consequently was much more gradual. They also found that the percentage of drivers making a full stop increased after the installation. (California, 1964, *52*)

7. Hoyt further supports the effectiveness of rumble strips with data from 22 approaches to nine rural intersections in Illinois. The combined accident experience at all nine intersections shows significant reductions in the ran-stop and rear-end-collision types of accidents, in total accidents, and accident severity. Nine other intersections with geometries, traffic volumes, and traffic control similar to the nine treated showed no significant increase or decrease in total accidents, accidents of a certain type, or accident severity during the test period. Hence, the accident reduction at the nine intersections with rumble strips was attributed to that technique. (Illinois, 1968, *79*)

8. Frequently, in rural areas, STOP signs are hidden by shrubbery or trees close to the roadway, telephone poles, etc. In most instances, the signs are preceded by intersection cross signs and/or STOP AHEAD signs, but many theorize that these signs are frequently not processed by the driver due to the abundance of them, even on rural highways. Figures A-33 and A-34 show two views of the approach to an intersection of a state highway with a U.S. highway in Pennsylvania. Unfortunately, this approach is on a relatively steep downgrade where stopping distances are relatively long. If the driver is unfamiliar with this intersection and continues at normal speed until the STOP sign becomes visible, there is no chance that he will be able to stop before entering the cross traffic. This intersection was selected by the Pennsylvania Department of Highways as one with high accident experience, suitable for the evaluation of use of colored pavement on stop approaches (see Appendix K). (Pennsylvania, 1969, D)

9. Figure A-35 shows a T-intersection stop approach with the STOP sign on the right (required by law) supplemented by a center-mounted STOP sign. It can be seen that an obstruction marker (with retro-reflective buttons) is mounted below the directional arrows in order to increase the night visibility of the situation and provide the driver with slightly earlier warning that the intersection is of the T variety. The visibility and T designation are further enhanced by the use of reflectorized white paint on the guardrails. The curbing and median island are treated with yellow paint, which is typical of North Carolina practice. (North Carolina, 1969, B)

10. Center-mounted STOP signs, such as shown in Figure A-36, are commonly employed in rural areas of North Carolina. Normal practice is to mount the sign on a 4 × 4-in. wood post in a small island created by backfilling a yellow-painted asphalt dike. It is believed that this location substantially improves visibility and precludes the type of problem illustrated by Figures A-33 and A-34. It should be noted, however, that the center-mounted STOP sign is usually used in conjunction with one placed in the typical position on the right, as shown in Figure A-35. (North Carolina, 1969, B)

Synthesis and Evaluation

As in the other situations discussed thus far, the critical information requirement in the stop approach is advance warning. Generally, this is provided through the STOP AHEAD or symbolic intersection sign, or, where the signs are not warranted, by a direct view of either the stop limit or the STOP sign.

The need for advance warning is particularly acute in rolling or mountainous terrain where the stop situation is on the downstream side of a crest vertical curve. In these situations, the driver cannot depend on the direct view of the stop limit or the familiar red octagonal-shaped STOP sign. In many cases where the warning signs are not warranted and alignment is relatively good, the direct view can be obscured by roadside obstructions such as trees or route markers.

The STOP sign may not be detected because of insufficient contrast with the background. Inspection of one high-accident location in Pennsylvania revealed that a driver approaching the angled T-intersection could easily believe he was on a through road that curved gently to the left. The STOP sign lacked target value in this case because it blended with a red-and-white service station on the far side of the cross road.

Given that the driver has processed a requirement to stop, he must then assess the available deceleration area and modify his position and speed to effect a smooth deceleration. Corrective maneuvers usually take the form of deceleration in gear, followed by braking action when the location of the stop limit has been determined.

Varying degrees of effectiveness are reported in the literature for the rumble strip and colored pavement treatments, depending on which evaluation measures are employed (approach speeds, accident incidence, accident type, lateral placement, etc.) In general, proponents of the rumble strip claimed favorable results. However, the color pavement issue is still somewhat ambiguous. In general, the studies have been limited to a few special problem

Figure A-33. Stop approach (distant view), Pennsylvania.

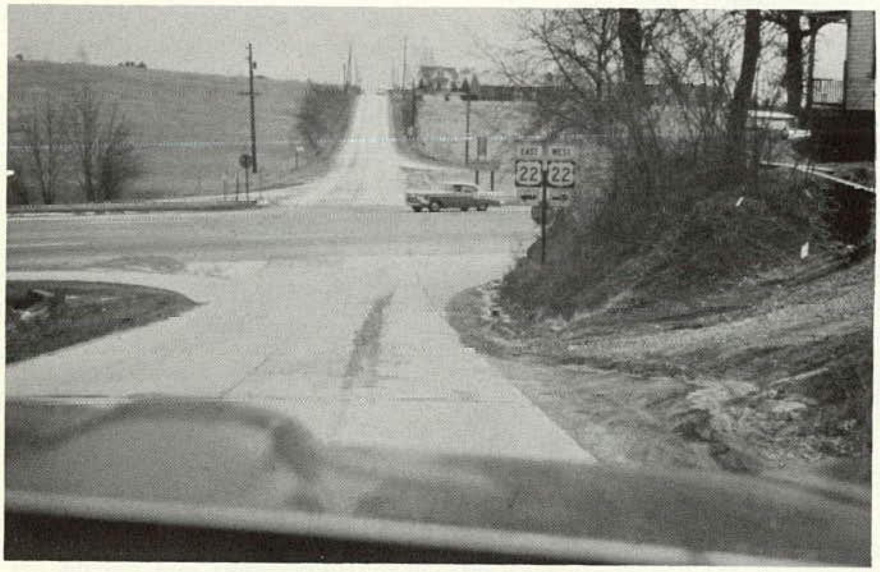

Figure A-34. Stop approach (near view), Pennsylvania.

situations. To date, no statistically significant accident rate reductions have been encountered. It would seem that, if color visibility can be provided both day and night, the red surface would be more than adequate not only in conveying the advance information (since the upstream edge of the pavement is visible at considerable distances, depending on the geometry), but also in defining the available travel path and hopefully minimizing shoulder and median encroachments. (See Appendix K for related studies.)

The perceptual modification technique used in rumble strip treatments would appear to be potentially effective in controlling approach speeds. This same principle might be applied to spacings of raised pavement markers or post delineators such that deliberate distortions in relative motion between the vehicle and the markers (or post delineators) would produce the desired deceleration profiles. Although the latter treatments cannot qualify as standard for stop approach situations, it would seem that these reflective devices, coded red and formula-spaced, might function as appropriate delineation treatments for this situation. (See Appendices G and P for related studies.)

Suggested Research

Suggested research relevant to delineation of stop approaches includes:

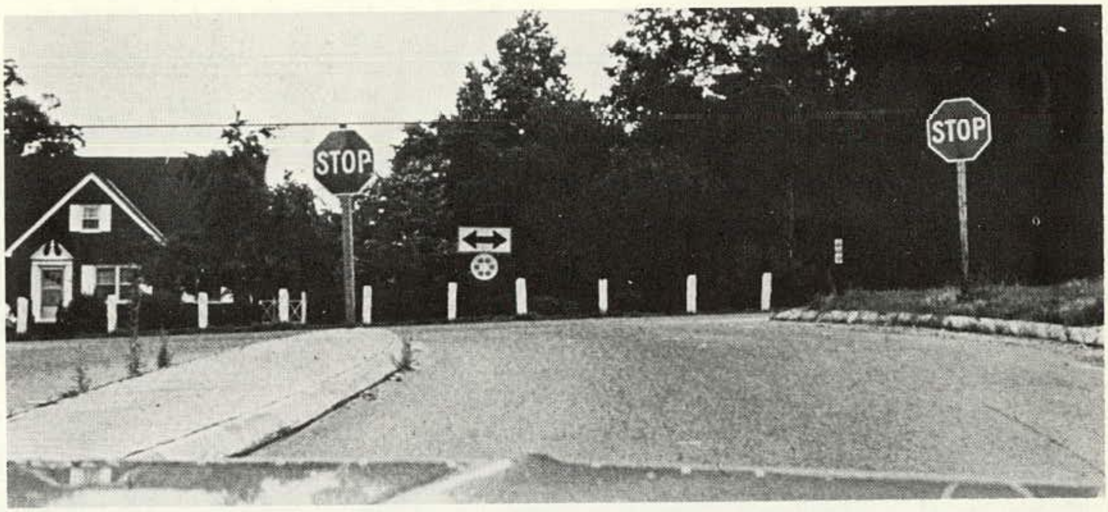

Figure A-35. Stop approach at T-intersection, North Carolina.

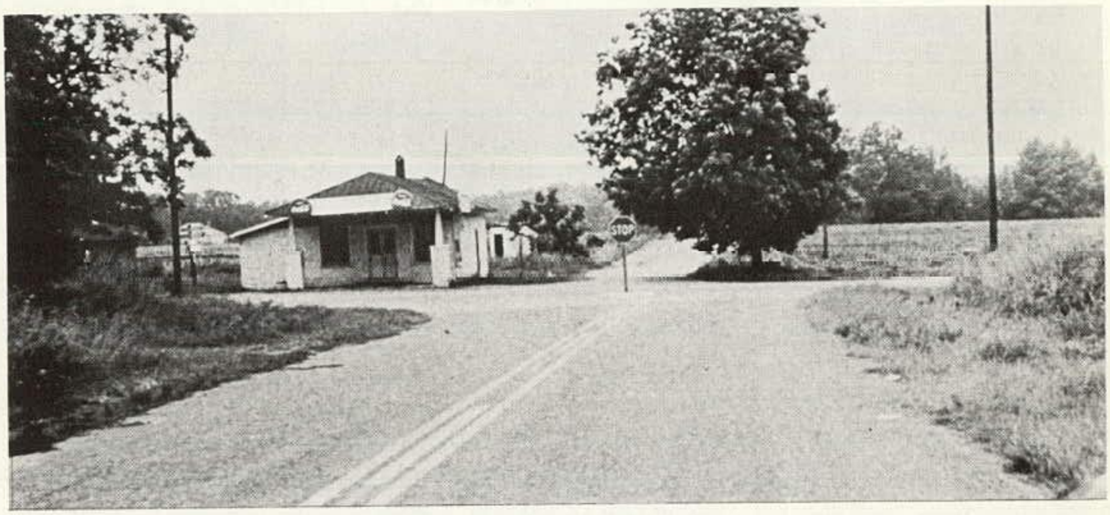

Figure A-36. Rural center-mounted STOP *sign, North Carolina.*

1. Comparative evaluation of painted transverse lines and audible rumble strips. Cost-effectiveness should be a major consideration in this study.

2. Investigation of the characteristics of intersections where high accident rates are experienced at STOP signs. It may be that certain factors (e.g., length of cross road visible while approaching the intersection, distance since the last STOP sign) are highly correlated with accident rates. In that case, the more expensive treatments could be applied in a selective manner.

3. The possibility of using coded, formula-spaced, post delineators and/or raised pavement markers to inform the driver that he is approaching a stop situation should be investigated. (See Appendices G and P.)

4. The distance back from the STOP sign at which the various treatments should be initiated is not adequately defined. Several of the high-accident locations cited by the Pennsylvania Department of Transportation are in open country, with long sight distances on the stop approach. Apparently, the information provided by the STOP sign (and any warning signs) is not being processed by all drivers. Perhaps a continuous information input (such as provided by colored pavement, rumble strips, pavement markings, series of reflective devices) is required rather than the discrete type of input provided by signs.

APPENDIX B

HUMAN FACTORS *

I. PERCEPTION AND INFORMATION PROCESSING

The study of roadway delineation system design, as conceived here, is based on the notion that the problem revolves around the driver, his needs, and his capabilities. Requirements for delineation are not based on characteristics of the roadway or the geometry of various roadway situations, but rather on the driver's need for information in order to maneuver safely and efficiently. Driving, it is fairly well agreed, is a predominantly perceptual task, involving constant perceptual reorganization of the environment and the driver's position relative to it. The driver must continually sample the vast variety of cues presented to him, interpret them, and act accordingly. To the extent that his sampling is effective, his interpretation correct, and his actions appropriate, his driving will be safe. If delineation systems are to contribute to the ease of the driving task and to increase the safety with which it can be accomplished, it is clear from the foregoing that they must be designed to take advantage of the driver's sensory and mental capabilities and to compensate for his deficiencies. To do this effectively it is necessary to assess, in the context of the driving task, the capability of the human to sense stimuli (mainly visual), to convert these into information (attach meaning), to use this information to make correct decisions, and to do all of these in a timely fashion.

This review attends to these questions by means of a selective survey of the psychological and traffic literature. It is concentrated in two major areas—vision and information processing. The number of potentially relevant studies is extremely large, extending from actual on-the-road performance to the truly microscopic level of neural anatomy and physiology. Rather than attempt to spread the coverage of this review over that range, a strategy has been adopted that limits consideration to the main sensory channel (i.e., vision) and to that portion of the information processing problem that deals with informational factors that can be, in part, controlled in the design of delineation systems and/or placement of the elements in the system. In short, the emphasis is on those characteristics of the visual and mental processes that can be expected to have relevance to the driving task and/or are related to the manipulable characteristics of delineation systems. How this strategy was translated in the actual operations of selecting and structuring the content of this review can perhaps best be explained by means of a brief examination of the driving task with emphasis on the role of delineation therein. (The general view of the driving task is developed in more detail in Section II of this appendix.)

As a driver travels toward his destination he is confronted by a virtually infinite variety of events (stimuli or cues). By far the greatest portion of these are visual, and because this is the major mode by which delineation operates, the other senses are not directly attended to here. The driver "sees" only a fraction of the total number of events. The "seeing" of events is determined by a large number of factors. Richards (*144*) expresses it as follows: "Seeing requires: Enough light, (intensity, pupil size) of proper quality, (image focus, size, brightness, contrast) long enough (absorption, to code nerve impulses) for perception (impulse integrated into consciousness) and interpretation (past experience)." This process is modified by factors such as acuity, glare, poor adaptation or color sensitivity, failure of the eyes to work together, fatigue, alcohol, drugs, motivation, emotion, age. As indicated by Richards' statement, the process is an integrated one; i.e., the sequence of stimulus, sensing, perceiving, interpreting is not in reality a set of separate steps; it is a process that includes both vision and information processing. The process, of course, ends in the appropriate response (or non-response) of the driver or subject. Selection of studies for the review was also, by and large, restricted to those studies using responses (or response measures) relevant to the driving task (i.e., tracking behavior, reaction time, etc.). The separation between visual input and information processing in this discussion is merely for convenience and clarity.

Given that the driver "sees" events, and noting that this all occurs within a real-time framework, he must process what he sees. A number of factors influence this activity. For example, the rate at which relevant and/or critical events occur can approach or surpass the driver's ability to handle them; the events seen can have multiple meanings and he may be uncertain as to exactly what they mean; for any particular event there may be a number of potential actions from which he must choose; a particular action may have to be accomplished very quickly. All of these factors, and more, affect the speed and accuracy with which information-bearing stimuli can be converted into appropriate actions.

VISION

The human visual sense can be roughly divided into three main parts—the eyes, the optic nerve, and the visual cortex. Intensive studies have been made of all three, permitting physiologists, neurologists, and ophthalmologists to describe with great precision the constituent parts and to explain a great deal about their workings. On a more macroscopic level, a number of review articles have been directed to the application of this knowledge to the driver and the driving task. Schmidt (*149*) begins with a comprehensive review of the physiology of the organ itself and then pre-

* By Robert S. Hostetter, Paul C. Harrison, and Edmond L. Seguin, Senior Research Associates, Institute for Research, State College, Pa.

sents a detailed discussion of eye movements, limits of the visual field, and the fixation field. Mullin (*119*) also discusses the gross makeup of the eye and continues to point out the importance of blinking. This phenomenon, although important physiologically in keeping the eye clean and moist, produces a measurable decrement in the efficiency of the human observer. Total time for a blink is between 0.3 and 0.4 sec, and since a blink occurs on the average of once every 2.8 to 3.8 sec, a decrement of 15 to 20 percent of all seeing time results.

Although any discussion of driver vision must of necessity address the problems of night seeing, it is Richards (*144, 159*) who takes this as his main focus. He, too, reviews briefly the physiology of the eye, but concentrates his discussion and synthesis of research on the transition from day to night, the magnitude of the decrement in visual efficiency in the upper scotopic and lower mesopic ranges and on the light available for night driving.

These authors (*119, 144, 149*) and a number of others (*112, 125, 137*) have also discussed the mechanical functioning of the eyes as a unit. Failures to operate in coordination, such as esophoria, exophoria, or lack of accommodation, and organic difficulties, such as loss of an eye, scotoma, or aniseikonia, are discussed in the context of loss of stereoscopic vision and, therefore, loss of binocular cues for depth perception. During daylight hours there are numerous powerful monocular cues for depth perception; however, at night many of these, such as relative size, overlay, contrast, are lost and stereopsis becomes increasingly important.

Although delineation is not solely a nighttime problem, there is little doubt that it makes a greater contribution at night. For this reason emphasis is placed on night (scotopic) vision and on the problems of seeing under conditions of low illumination. To illustrate the magnitude of the problem consider the following statements: "The man with 20/40 visual acuity by day will have less than 20/100 at night on the highway" (*112*). "Under road lighting conditions, the visual threshold, which is approximately 1 min of arc in the laboratory, will increase to 3 to 4 min of arc at best." "At night a driver may discover an object in one of three ways: (1) illuminated by his own headlight, (2) as a silhouette, (3) by hitting it. The third case is interesting because it occurs too often" (*146*). Legibility distance decreases 15 percent at night under optimum conditions, but may decrease as much as 90 percent in actual practice (*137*). "Seeing becomes less possible away from the main beam of the headlight. The eyes search futilely for a sensitive part of the retina to sharpen the blurred images" (*144*). "Night presents a new geometry" (*123*). In short, driving at night increases the problems of seeing many fold, and the characteristics of the stimuli must take this into account.

A number of attributes of stimuli can be manipulated to enhance the probability that they will be seen. Among those to which particular attention has been given are color, brightness, color contrast, brightness contrast, size, shape or form, pattern, and location. It is well known that color and brightness are interrelated and that sensitivity to different colors changes as the level of illumination changes (*158*). Contrast, under low levels of illumination, plays a more important role in legibility than acuity (*137*). Size is also less important than contrast or brightness because the distance of seeing an object on the road has been shown to be more a function of contrast (*112*) and a light smaller than 1 min of arc (threshold) can be seen if bright enough (*112*). Perception of form depends mainly on a sharp difference of brightness between an object and its background (*119*). Physical location of stimuli relative to the driver determine the area of the retina stimulated. This, in turn, influences the detectability, because peripheral acuity is, in general, measurably less than foveal acuity; e.g., a displacement of 12° from the fovea reduces acuity by 80 percent (*119*). As suggested by the preceding, the characteristics of stimuli are of great interest when considering the design of delineation systems, since this is one aspect that can be dealt with directly. Given a set of conditions and assuming some minimum level of visual capability in the driver population, it is possible to specify big enough, bright enough, and appropriately placed treatments to improve the probability that the stimuli are being detected in a timely fashion.

The problem of translating the detected or "seen" stimuli into the appropriate response involves paravisual factors. One that is of general concern and that requires some discussion here is the interaction of the "seen" event(s) and past experience or learning. Although this topic obviously involves "processing," it is included here because of the heavy dependence on what is "seen." For example, perhaps the most powerful cue in the estimation of distance is the perceived sizes of objects, and, in general, the accuracy of the estimate is related to the familiarity of the object. Other cues also influence distance judgments (e.g., distance perception is difficult in a "structureless" field; for instance, in the dark a stationary light is usually underestimated in distance (*149*); or, more relevantly, the distance of an oncoming vehicle or motorcycle in a nighttime passing situation). Familiarity (or lack of it) can influence the time required to see an object. About ½ sec of looking at an object is required for visual acuity to reach its maximum (*119*). Perception of unfamiliar patterns or words will be less rapid (than the 0.6- to 1.0-sec "glance" reading time) (*137*).

The perception of motion is also involved here. It has been shown that perception of motion is a retinal impression, but that the nature of the perceived movement depends on associations in higher brain centers (*149*). Motion in depth is particularly deceptive because there may be no displacement of the retinal image, but only changes in size, shape, etc. Binocular vision is better than monocular for these judgments, but not essential. In general, it can be said that use of the visual sense by the driver is complex and exactly how much is considered "vision" depends on where in the central nervous system the boundary between sensory and motor response is located. Even then, it must be recognized that the driver may see perfectly but fail to act, not be able to act in time, or be overpowered by the sensory input (*144*).

Acuity and Visual Field

The ability of the eye to resolve details is called acuity and is usually discussed in terms of threshold values of minimum size detectable or minimum separation resolvable. The most commonly cited value for visual acuity is an object or gap subtending 1 min of arc as the lower limit. This static acuity, or "office acuity" as it is sometimes called (*112*), is commonly measured by means of a Snellen chart at luminances of 10 to 30 fL and reported in terms of a distance fraction. Normal vision is 6/6 (meters) or 20/20 (feet) where the subject can read letters composed of bars subtending 1 min of angle at 6 meters or 20 ft and no better (i.e., further) (*119*). As Schmidt (*149*) points out: "Visual acuity (v.a.) is a complex function of a number of variables: sharper focus of retinal image; pupil size; illumination up to about 10 mL; contrast; retinal region; interpretive functions of the brain; relative motion; color of the stimulus." Other authors add to this list physiological and psychological factors such as disease, drugs, alcohol, boredom, and fatigue (*119, 144*), and physical factors such as vibration, dirty windshields, fog, and glare (*146, 149, 182*).

Although it is clear that the biggest decrement in the driver's visual acuity comes as a result of lowered illumination at twilight and on into the night, it is also clear that little can be done about it because providing sufficient artificial illumination is totally impractical. Given, then, that the nighttime driver has an operational visual acuity of from 1/5 to 1/20 of "normal" just from lowered illumination, there are other factors that operate to decrease even more his effective level of seeing. Two of the most pervasive of these are relative movement and stimuli falling outside the fovea or central cone of vision. Thus, dynamic visual acuity (DVA) and peripheral acuity are important considerations.

Dynamic visual acuity, as it has been called by Ludvigh and Miller, refers to the resolving power of the eye when there is relative motion between the observer and the object. Relative motion exists when the observer, the object, or both, are moving. Measurement techniques have been developed where the object is moved at a constant speed and the size of the target is varied until it can be resolved and where the target size is constant and speed is varied until the target can be identified. Both of these standardized techniques involve a stationary observer. Another measurement variable that has been shown to have an effect is whether head position is fixed or not (acuity measures improve with head free) (*154*). There are those, notably Mullin (*119*), who contend that the test, if it is to be related to drivers, should involve a moving observer because this would bring into play all the apparent movement in the periphery and the accompanying cerebral confusion. He suggests, not altogether facetiously, that employing an amusement park device where centrifugal force pins the riders to the vertical walls, "it would be of interest to test [acuity of vision] by flashing Snellen cards across the line of sight at irregular intervals . . . [and] . . . noise might accompany the test and the observer be required to peer through a wet windscreen." In spite of the suggested possibility of different results with a moving observer, it is still apparent that any test involving relative motion is likely to be more closely related to the visual task of the driver than is the conventional Snellen chart static test.

Feldhaus (*116*), reporting on the Ludvigh and Miller investigation where the aim was to assess DVA as related to angular velocity, translates these findings into acuity at various speeds. For the data reported he concludes that at 60 mph and looking at an object 20 ft from the car, a driver's acuity will range from 20/121 to 20/317. Corresponding values for 30 mph will be 20/70 to 20/150. Feldhaus also points out that there are wide differences among individuals in the rate at which acuity deteriorates with increases in angular velocity. Furthermore, people with similar static acuity may have significantly different DVA. This suggests that unless DVA tests are integrated into licensing procedures, considerations of acuity are not appropriate to design of delineation treatment (or that a large "safety" factor be used).

Another study, reported in the same year as the Ludvigh and Miller work, by Burg, et al. (*164*), assessed the test-retest reliability of DVA and attempted to relate measures of DVA to the performance of various tasks. The acuity tests employed the Bausch & Lomb Ortho-Rater checkerboard, rotated the projector, and projected the image on a semicircular screen. The range of angular velocities tested was 20° per sec to 180° per sec. In general, they found that DVA scores were not predictable from static acuity for angular velocities above 60° per sec, which seems to indicate that a previously unmeasured aspect of vision unrelated to static acuity is operating. In terms of the relationship between DVA measures and sign reading (projected pictures of signs) no striking predictive power was revealed, but the data suggested to the authors that DVA was more closely related to the task than was static acuity.

In a later paper, Burg and Hulbert (*154*) continued to study the relationship of DVA and static acuity and expanded their concern to include other measures of visual functioning, such as critical flicker fusion frequency and lateral phoria, and nonvisual factors, such as age and sex. DVA measures were also taken with free and fixed head position. Their findings showed little relationship between flicker or phoria and any other measures, nor were age differences noted (due to restricted age range in sample). Of particular note is the fact that low but significant correlations between DVA and static acuity were found. These tended to be higher when free head movement was allowed and in general decreased with increasing target velocity. Test-retest reliability was significant for free-head DVA, but not for fixed-head DVA. This, coupled with the fact that freedom of head movement is characteristic of the driver performance situation, argues strongly for standardizing on this technique.

Wiessman and Freeburne (*160*), in a similar study, but using a different measurement technique, found essentially the same results. DVA measures showed a high degree of internal consistency and were correlated significantly with static acuity except over 150° per sec angular velocity.

Another common finding replicated here was that DVA decreased markedly as a function of increasing velocity.

In several of the preceding studies, mention was made of the fact that it would be desirable to obtain normative-type data for DVA. By 1966 this had been accomplished by Burg (*155*), who reports the results of DVA tests on 17,500 California drivers split approximately ⅔ male to ⅓ female and ranging in age from 16 to 92. Measured static acuity ranged from 20/13 to 20/200. The results confirm the earlier findings with respect to increasing velocity, the relationship of DVA to static acuity (which the author attributes to non-acuity factors), and the decreasing strength of the DVA/SVA relation with increasing velocity. In addition, it is shown that, like static acuity, DVA declines with age, but appears to do so at a greater rate.

The other previously mentioned factor that bears heavily on the "working acuity" of the driver is the location of the stimulus image on the retina. If it falls outside of the fovea or parafoveal region (up to about 4° surrounding the fovea), acuity is markedly less. Inasmuch as it is well known that the binocular visual field (with eyes fixated straight ahead) for most people is approximately an arc of 120° (*144*), it is immediately obvious that much of the visual stimuli are "seen" only imperfectly. Perhaps the first question is how imperfectly: If foveal acuity is considered 100 percent, then a displacement of the image as little as 10° in any direction will result in a measured acuity of 20 percent or less. Given that the average two-lane road subtends an angle of approximately 30° at 25 ft from the car, it is also obvious that much of a driver's seeing is done under severe handicap. This fact is underscored by the observation (*112*) that the eye using central vision can fixate on the road only once in every 22 ft of travel at 60 mph. Another complicating factor is that the 120° of field referred to exists only with a static observer in a free field. The driver, encased in an automobile moving along the highway, has effectively much less field. Considering the limitations imposed by the vehicle, the binocular field outside the car shrinks to a rough rectangle approximately 30° vertical by 120° horizontal, and even this has blind spots imposed by door posts and rear-vision mirrors (*144*). In addition, one must include the effects of speed; Schmidt (*149*) cites the work of Kite and King, which showed that at 60 mph the effective field narrows to approximately 42°. The ultimate shrinkage occurs at night where the effective field (for all except bright lights) is in the area illuminated by the headlights—approximately 5° by 8° (*159*). Note that if an individual's field of view were this restricted all the time he would be said to suffer from acute "tunnel vision."

Before leaving the subject of restrictions on the visual field, it should also be noted that many authors list additional factors that can further adversely affect the size of the field, such as smoking, carbon monoxide, wide-temple eyeglasses, and drugs (*112, 144, 149, 159*). One other limiting factor that has received considerable attention is age. In a report published by the American Automobile Association (*169*), the results of tests on 1,279 persons ranging in age from 15 to 70 years old indicated that there is a consistent trend for the visual field to decrease with increasing age. In a study by Wolf (*189*), critical flicker fusion frequency and dynamic visual acuity were tested at five points on each of the four principal radii of the field. Performance in both measures decreased with increasing age, and for DVA in the periphery 20 times as much light is required as for static acuity at the same point.

Having outlined the general confines of the peripheral field and noted some of the major restrictions on it, the question remains regarding how the driver employs what little peripheral vision he has and what are the limits of his ability to do so. Basically, the periphery acts as a gross detector, alerting the visual system to the fact that there is something there: to discover what it is that is there usually requires a direct look using central vision. As the driver proceeds along the highway, he requires information or cues that will assist him in selecting his path and in avoiding obstacles. He must search for these cues, and inasmuch as he can only sample (using direct vision) he must rely on peripheral vision to enhance the quality of his sample. Johnston has investigated the role of peripheral acuity in search performance in both close (*178*) and far (*179*) vision. In the first case 36 subjects were tested for visual acuity, visual field, and two search tasks; both the size of the display and the number of items contained therein were varied. From the results he concluded that the larger an individual's binocular visual field the more rapidly targets can be detected; however, both the size of the display and the type of target affect search time. The second study (*179*), which attempted to relate peripheral acuity to far-vision search performance, employed roughly the same number of subjects and essentially the same measurement method. The results, however, revealed only negligible correlation between measured acuity and the search tasks. It might be pointed out that this finding is neither totally unexpected nor indicative of a particular handicap for the driver. First, when one is searching at long distances ahead (1,000 ft or more) the actual field of interest (the road and immediate surroundings) is fairly well confined to the parafoveal region; second, peripheral search in the middle range (25 to 1,000 ft) is aided by the relative movement, which increases in angular velocity as the driver gets closer to any given object, and the rods of the peripheral retina are better at detecting movement than they are at resolving detail. Erickson (*168*), in a study similar to Johnston's near-vision work (*178*), found correlations significant at the $p < 0.01$ level between peripheral acuity, measured at 3.6° and 4.8° from the visual axis, and time to find a target in a complex display. Also noted in the findings were the influences of target type and complexity. Age and foveal acuity were not correlated with either peripheral acuity or search time.

This lack of correlation between foveal and peripheral acuity was investigated in somewhat more detail by Handel and Christ (*176*). They studied the detection and identification of regular geometric forms presented centrally and 4.75° peripherally on both nasal and temporal sides. The detection task involved measuring exposure time necessary at each of the three viewing positions for 80 percent accuracy of detection of the presence of a known shape.

Identification involved determination of exposure time for 50 percent accurate naming of the randomly ordered presentation of five different shapes. Results in general showed negative correlations between foveal and either peripheral score and high positive correlation between the temporal and nasal peripheral performance on both tasks. One additional interesting note: of all shapes, the circle was easiest to detect and identify at all viewing positions.

At any time the identification of the peripheral stimulus is required, it is necessary for the observer to move the eyes and fixate the target in his central vision. This implies a number of separate factors that may influence the speed and accuracy of the performance. Assume a subject is seated with eyes fixated on a target directly on the visual axis. Upon presentation of a peripheral stimulus, there will be some time elapse before it is peripherally perceived; more time will elapse while the eyes move to fixate on the target (a movement that may overshoot or undershoot); once the eyes are fixated, a measureable amount of time elapses before the stimulus is centrally perceived and responded to.

Bartlett, Bartz, and Wait (*192*) investigated the time components of the foregoing sequence. In their first experiment the observer was seated with his head rigid before a horizontal array of Nixie tubes spaced right and left from center at 2.5°, 5°, 10°, 20°, and 40°. With the observer's eyes fixated on center, a random signal [random presentation tends to decrease accuracy and increase time (*180*)] was presented in the periphery. The observer was required to move his eyes and identify the number displaced. In general, response time increased as a function of displacement from center and the number of possible response alternatives. In the second part of the study, essentially the same procedures were used and components of the total response time were measured. The same trend was found in each of the component times as was typical of the total response time; i.e., time to detect, time to move, and time to interpret all increase as a function of angle of displacement and response complexity. In a later study, Bartz (*162*) expanded the analysis to cover the accuracy with which these movements take place. Electrodes were taped to the external canthus of each eye and the resultant signal was amplified and displayed on an oscilloscope. By these means it was possible to detect both undershoots and overshoots of eye movement and to measure the elapsed time of the initial fixation after movement. The results showed that more total errors occurred as the degree of displacement from center increased. The initial fixation time was found to be essentially a constant, and overshoot error occurred about equally at all position, whereas undershoot occurred more at the extremes.

As might be expected, the subject of eye movement time, accuracy, and fixation time has received a great deal more attention than can be covered in detail here. Richards (*144*) presents in table form a comprehensive review of much of this work, with an emphasis on application to the driver situation.

Environmental Effects on Acuity and Visual Field

As alluded to previously, the most serious environmental effect influencing acuity of drivers is the reduced illumination that is available for driving at twilight and at night. In the words of Richards: "At dusk seeing becomes difficult. The sky is still bright . . . and veils the field of view with glare . . . the glare and smaller amount of visual information handicaps the judgment of depth and of position and speed of vehicles. With greater darkness, changes appear more rapid and momentary. . . . With darkness the broad fields of view of daylight close into the region illuminated by the headlights . . . the night driving fields of view are smaller, the visual content of the field changes rapidly and the information received is more concentrated. Values change, colors fade, resolution decreases and pattern predominates. . . . The world appears unreal and ghostly." (*159*) Substantiating this descriptive narrative of the driver's plight is a mass of data, which, when taken together, appear to indicate that just as it is aerodynamically impossible for the bumblebee to fly, it is visually impossible for man to drive at night. Of course, the bumblebee does fly and man does drive at night. It is, however, also true that the task is more difficult, and a substantial driver performance decrement appears to be indicated by the 250 percent increase in the accident rate at night (*151*). Although it has not been possible to directly relate accidents to faulty vision, logic demands that attention be given to this factor as a potentially major contributor.

Numerous studies have sought to relate performance of various visual tasks to varying amounts of available roadway illumination. Typical of these is the work of Blackwell, et al. (*114*, *123*), and Bonvallet, et al. (*163*). Basically, these studies involve the determination of the visibility of various objects on the roadway. Parameters such as color, size, contrast, background, distance, and type and amount of illumination were systematically varied. The results indicate that contrast, more than small increases in luminance, appears to be the most powerful determinant of visual performance. White targets (i.e., higher reflectance) are more easily seen. Silhouette viewing is a major aid in seeing darker objects. Finally, the illumination required to obtain a given level of performance varies widely from task to task.

Another source of light that may or may not help the driver/observer is that provided by headlights of oncoming traffic. Schwab (*150*), using the Visual Task Evaluator, conducted a study of this phenomenon. The targets to be seen were a red reflector on a black unlit car at 500 ft and a standard pavement paint stripe at 200 ft. High and low beams were used and separations between cars (both lateral lane position and longitudinal distance along roadway) were systematically varied. The conclusions support the importance of contrast and note the trade-off between visibility and glare with high beams vs low beams.

Rumar (*146*), having established on the basis of earlier work (*177*) that visibility of objects illuminated by headlights on a dry, non-illuminated road is directly related to the reflectance of the object, extends these results to wet and snowy roads. A 140 by 49-cm object, with varying reflectances of 3%, 8%, 16% and 82%, was employed as a target. The subject drove toward the object using low beams, stopped when he saw it, and backed up until he could just barely discern it. The results indicated that for wet roads the relation between reflectance and visibility is even stronger than for dry road; on snow it is less than for dry road, but in the same direction. As for the importance of contrast, the over-all results seem to be better explained in terms of luminance differences.

A different approach to this general problem has been developed by Rockwell, et al. (*145, 183*), who have systematically varied illumination available at the eye and measured its effect on actual driving performance under varying task instructions. The tasks involved actual highway driving and varied emphasis on speed and placement in lane. In general, performance was markedly consistent regardless of illumination—a finding that was interpreted as support for the importance of contrast. It was also suggested that much of this essential contrast is provided by the edge line/lane line. Later work in this series has tended to confirm this suggestion.

Another instance of an actual driving task used to assess the effects of lower illumination is the use of a day/night comparison of gap acceptance behavior at an intersection (*121*). The data were drawn from observation of actual traffic and showed small but significant differences between night and day for two levels of traffic volume. It can be concluded from the observations that at night headways tend to increase (a higher percentage of long gaps) and the critical gap acceptance size is larger. Apparently, drivers make some allowances for the lesser speed and accuracy of perception.

A less experimental but no less viable expression of concern for this problem is reflected in the large number of "treatment"-oriented articles. Selected as typical of this approach is an article in *Traffic Safety* (*142*) and a paper by Sielski (*151*). The former emphasizes the importance of reflectorization in general and "guide lines" in particular. Surveys and accident data from several states are cited indicating dramatic decreases in accidents. For example, one 8-mile segment of Utah highway had 29 accidents in 9 months prior to edge lining and only 8 accidents in the subsequent 9 months. Sielski cites a number of the factors that affect accuracy of visual perception and recommends specific remedies that include overhead illumination wherever possible (and cost effective), illumination or reflectorization of all vital signs, and reflectorized edge lining. He also stresses the need for delineators at curves.

A specific problem that is referred to in many of the previously cited studies is the maintenance of appropriate levels of dark adaptation, particularly in the face of oncoming high-beam headlights. Studies by Brown (*218*) and Kinney and Connors (*181*) have addressed this issue directly. Brown discusses the problem in reference to pilots and a military application, but portions of the data cited are appropriate to the driver's situation. The Kinney and Connors study employed intensities of 0.3 to 3,000 fL and durations of 1 to 45 sec. The readaptation curves that are reported indicate that time to readapt is directly related to both the intensity and duration of the exposure, ranging from essentially zero for a dim brief flash to a maximum of about 5 min for the longest brightest flashes. Interestingly, it was noted that the product of time and intensity is essentially constant and when readaptation time is plotted against it a single curve results that fits the empirical data well.

The environmental effects category is one that some authors have seen fit to enlarge to cover some of the driver's self-imposed environment (as, for example, tinted glasses and tinted windshields). These devices, which have an apparent daytime utility, have been shown to be potentially hazardous at twilight and at night. One study (*187*) using artificial illumination involved measures of detection in the presence and absence of glare. Not only was there no measurable advantage in sunglasses in the glare condition, but visual detection efficiency also was lowered by their use in both cases. Another study by Wolf, McFarland, and Zigler (*190*) tested five visual functions as influenced by tinted windshield glass and, in general, found no measurable benefits from its use. As in the Raphelson, et al., study, reductions in threshold equivalent to the light-absorbing power of the glass were noted. As Richards (*159*) explains it, "At night, seeing and stopping distances become about the same at some speed (sometimes under 50 mph). At this point the loss of even a very little light from any absorbing glass may result in a rear-end collision."

Characteristics of Visual Stimuli

The design of delineation systems can be viewed, in the context of this discussion of man's visual processes, as the specification of stimulus characteristics such that the probability of detection will be enhanced, the perception of the boundaries of the field of safe travel will be accurate, and the interpretive functions based on these perceptions will be accomplished with minimum error. It is apparent from the foregoing that it is necessary to review in some detail the more important stimulus characteristics such as brightness, color, brightness contrast, and color contrast, and to ascertain as precisely as possible how they relate to each other and to the capabilities of the driver and the limitations imposed by the road environment.

Brightness * as a factor in delineation evaluation cannot be considered independent of brightness contrast. Obviously, the object (or treatment) to which we want to draw the driver's attention must be easily discriminable from the background against which it is used. Brightness contrast is generally given as $BC = (B_o - B_s)/B_s$, in which B_o is the luminance of the object and B_s is the luminance of the background (*144*). In some cases one will be dealing with a manmade background, such as a section of asphaltic pavement or a sign. In other cases one must deal with a natural background over which there is little, if any, control. The latter will vary over a wide range of textures, colors, and reflective characteristics. Further complicating the problem is the wide range of illumination conditions under which a given treatment will be used (i.e., from natural bright sunlight to darkness; a range of types and intensities of luminaries; and high- and low-beam headlights of varying intensities). Finally, the ambient illumination and/or direct light will produce a given level of adaptation in the eyes, thereby changing perception of brightness and contrast as conditions vary. It is clear that

* *Brightness* is a perceptual term that is used to describe how an object of a given luminance appears to an observer. Where actual measurements have been made, the term *luminance* is typically used.

at any given level of brightness for a treatment, the background and conditions of use will vary so much as to make it virtually impossible to specify satisfactory over-all brightness values. Thus, the problem facing the engineer is one of deciding which trade-offs to make under a specified set of conditions. Inasmuch as color coding is frequently used in delineation treatments and delineation-related signs—and is a prime candidate for more frequent application—color and color contrast effects are also important considerations.

Basic physiological and perceptual data regarding the effects of these factors are available in several excellent handbooks and texts [e.g., Stevens (*152*), Geldard (*128*), and Koch (*139*)]. Therefore, this review is restricted to applied studies.

Unfortunately for the particular needs of this project, most of the basic human factors applied research in this area is focused on roadway signs rather than delineation treatments per se. However, because these studies deal with the physical principles of brightness and contrast and many of them involve evaluation of reflectorized materials, some generalizations to other treatments should be possible. Before discussing the studies, it may be well to review for the reader not familiar with the physiological and perceptual details of vision some basic facts related to brightness and contrast.

First, there are two mechanisms by which the retina of the eye is brought into balance with light conditions: (1) the pupil reacts reflexively, getting larger or smaller, to control, in large part, the amount of light striking the retina; (2) the retina becomes more or less sensitive in the presence or absence of light. The loss or gain in sensitivity is known as light or dark adaptation and is a more slowly reacting mechanism than the pupilary reaction. As a point of reference, it is of interest to note that after ½-hr exposure to dark (the usual time for full dark adaptation) the retina may become responsive to light that is 1/100,000 of the intensity originally necessary to stimulate it (*128*). The interaction of adaptation and perceived brightness is obvious. Richards (*144*), in reviewing data on adaptation levels of night driving, reports that Davey (in *144*, p. 45) estimates that it would take approximately 5 min. to adapt from the relatively high illumination of city streets (0.001 to 0.03 fL) to the illumination of country roads (0.0015 to 0.0017 fL). If these data are accurate, it would mean that at 60 mph a driver may drive slightly more than 5 miles before his vision would be normal with respect to adaptation. The relationship between adaptation, brightness, and acuity as discussed in the Allen and Straub review (*161*, p. 2) is such that for the adapted eye, acuity increases with increasing brightness of the test object. Although there is variation with specific test objects, in general at higher levels of brightness the acuity curve levels off, and further increases in brightness yield little increase in acuity. However, the point at which the acuity curve levels off depends on the adaptation level of the eye. Further, if the brightness exceeds the adaptation level, further increases will cause a decrement in acuity. This latter point is illustrated by the fact that if a driver whose eyes are adapted to a fairly low level of nighttime illumination encounters a sign of very high brightness, irradiation * will occur and have a severely detrimental effect on letter legibility (*161*, p. 3).

Allen and Straub (*161*), in a review of the literature related to sign brightness and legibility, point out that up until the date of the review very little research on the legibility of reflectorized signs had been reported. They criticize the only (at that time) recent study on reflectorized signs that had been done, stating that the experimental design and the photometric measurements were inadequate for explaining relationships between legibility and sign brightness. For these reasons it was decided to restrict the review of brightness/contrast to selected articles from the period 1955-1969.

Allen and Straub (*161*) used both a laboratory and a field experiment to investigate the singular and combined effects of the four factors they believed were of primary importance to the night legibility of signs—sign brightness, the level of illumination to which the eye is adapted, characteristics of letters, and contrast direction (i.e., black letters on white, or vice versa). The first two factors are relevant to delineation treatments in general. For the field tests, the authors concluded that illumination conditions surrounding a sign are important. No general conclusions regarding sign reflectance could be made from the data; however, there were indications that for the high-reflectance sign there may be an irradiation problem with smaller or narrower numerals.

In the laboratory test, each of the four factors was shown to be important in terms of night legibility. Legibility distances for various combinations ranged from 22 ft (Series A letter at 0.1 fL) to 92 ft (Series F letters at 100 fL) per inch of letter height. For the high level of illumination, increases in brightness resulted in greater increases in legibility than for the low level of illumination. White letters on black were more legible at 10 than at 100 fL, indicating excessive irradiation at the higher level.

In a later study by the same authors (*188*), a method for calculating the brightness of reflective material for a given distance and placement is described. They point out that the same methodology, in addition to being used for signs, could be applied to related problems, such as reflectorized pavement markings and reflector buttons. The method was applied to five common types of reflective materials: (a) beads on paint, (b) beaded sheeting, (c) flat sheeting, (d) thin-lens mirror, and (f) thick-lens mirror.

It was found that, in general, highway signs have low luminance at near distances and maximum luminance at distances from 150 to 508 ft, and again decreasing luminance at greater distances. Letter size was found to be of great importance in the selection of reflective material. For signs with small letter size it was found that little is gained by using the expensive high-brightness materials because: (a) small letters cannot be read at great distances no matter what the brightness, (b) adequate brightness is easily achieved using any material at near distances where illumination from headlamps is high, and (c) little

* Given a white-on-black sign, the eye sees a spreading of the white at levels of brightness exceeding adaptation. This spreading of the white is known as *irradiation*.

increase in sign illuminance is achieved through high-brightness materials because of the large divergence angles encountered at short distances. However, for large signs to be read at great distances, the more expensive materials may be economical; i.e., because little light reaches the sign from the headlamps, high-brightness materials are needed to achieve adequate luminance for good legibility.

It was also found that the height of the sign is a more important factor than lateral placement. With respect to the effect of curvature of the road on sign brightness, it was found that for a sign mounted beyond a summit, sign luminance is always greater than on a level road. The authors state that this would be the critical position for a material that might be too bright for good legibility. For a sign mounted beyond the sag, however, it was found that luminance is always less, and significantly so if the vertical curvature is abrupt or if the sign is to be read at a long distance.

Horizontal curves were found to cause a marked reduction in sign luminance because signs on curves are outside the main portion of the headlight beam. Thus, the illumination reaching the sign is reduced to as low as ¼ of the straight road value on a 6° curve. On horizontal curves a special problem arises from use of reflective materials that are sensitive to changes in entrance angle. The results taken on curves are of particular interest here due to the fact that some states are using signs as opposed to post delineators for marking the curves. These results indicate that much more care must be taken in selecting signs with the appropriate reflective characteristics (i.e., those not sensitive to change in entrance angle). Otherwise, the lack of care in aiming can result in a serious loss of brightness and may make the delineation treatment inappropriate. It will be noted that the aiming referred to here is that of placing the sign in an appropriate orientation with respect to the roadway and the driver.

Elstad, Fitzpatrick, and Woltman (*165*) present data that describe the effects of changing divergence angle and headlight luminance within the sign field. They state that when these data are coupled with knowledge of specific luminance, reliable calculations of reflective traffic sign luminance can be made. Their calculations from field measurements indicate that normal shoulder-mounted reflective signs provide luminances of 1.5 to 3 fL with low beams, and 10 to 50 fL with high beams at generally useful legibility distance. Field measurements in rural and suburban surroundings show that ambient luminance on signs can range from negligible to 0.4 fL. In these environments sign luminance of 10 to 20 fL provides optimum brightness for maximum legibility. They found that the use of low beams results in 85 percent of the maximum legibility figure. For the legibility tests the modified BPR Series E illuminated letters on a dark background were used.

Forbes, et al. (*171*), used simulated "Interstate green" signs of varying brightnesses against typical highway backgrounds. In this study subjects were asked to indicate which sign they could see best under various conditions and were simultaneously required to engage in an auxiliary task involving fixating on and responding to small red lights. This study was designed to determine the effects of sign position and brightness in relation to ease of seeing signs under simulated highway conditions. The purpose of the auxiliary task was to load the subject and to assure visual fixation at the road level on the projected highway scene. The aim of the study was to control as many variables as possible so as to measure the probability of a sign being seen. The authors state that the purpose was not to measure the distance at which a sign first became legible, but rather to determine whether the sign was more or less likely to be seen among other signs and background objects when suddenly exposed to view in traffic situations, such as emerging from behind a large truck, coming over a hill, or rounding a curve.

From the group of five experiments, the authors concluded that the signs highest in brightness were seen first most frequently against night backgrounds. The lower-brightness signs were seen first most frequently against the day-snow simulated backgrounds, but some subjects saw the high-brightness signs first against these backgrounds also. Conditions simulating a sign against the hill showed brighter signs to be advantageous.

Powers (*186*) performed a field study in which subjects drove over highways and parkways on which the routes were marked by test signs placed in advance of exits. An observer riding in the car noted missed turns and directed subject drivers back to the appropriate route. In this study Powers used three degrees of reflectorization: (a) non-reflectorized green background, (b) moderately bright reflectorized green background, (c) high-brightness reflectorized green background. The results showed that there is no difference between the levels of reflectorization tested. These results are, in general, inconsistent with other studies of the effects of reflectorization of signs and perhaps represent the difference between laboratory and field tests; that is, field tests using a real driving situation.

Pain (*185*) did a study to evaluate the effects on attention value of: (a) brightness when brightness ratio was held constant; (b) brightness ratio when brightness was held constant; and (c) stimulus brightness and brightness ratio when both were varied simultaneously. He also sought to determine if higher relative brightness would enhance the attention value of any brightness ratio and if eye movement measures would correlate with subjective responses. One of the purposes of this specific arrangement of independent variables used by Pain was his criticism of a number of other studies that stimulus brightness and sign-to-background brightness ratio were always confounded; i.e., although brightness was varied, background intensity remained unvarying. Pain points out that in the area of perception the work of Blackwell on contrast thresholds and Jameson and Hurvich on brightness matching at various contrast levels indicated that stimulus brightness and contrast interact in their effects on perception.

It was found that either brightness or brightness ratio, when present as the only variable, had equivalent attention gaining value. For each, the attention value increased in a rapidly accelerating manner as the variable value is increased. When brightness and brightness ratio are present together, brightness ratio receives more attention. However, a high relative brightness enhances the attention gaining effect of brightness ratios. Pain points out that this was more evident for the negative contrast direction (background brightness levels in the day-driving-to-twilight range) than for the positive contrast direction (night-driving background brightness levels). With respect to the subjective reaction measures as compared to the eye movement measures, it was found that the subjective measures were most consistent. Although the three eye movement measures taken were highly correlated with each other, they were not highly correlated with the subjective reaction measure. However, as the number of dimensions varying concommitantly increased, the correlation between eye movement and subjective reaction measures became high.

Forbes, et al. (*170, 172*), in a continuation of the series of studies reported previously (i.e., *171*) studied letter and sign contrast brightness and size effects on visibility. The separate experiments reported on in this paper were as follows: (1) effects of sign size and brightness with constant letter brightness, (2) effects of sign size and brightness without letters, (3) effects of sign size and brightness with reducing letter brightness, (4) effects of sign size and brightness in competing illuminated signs. The first three experiments confirmed previous results indicating that the darkest of four signs was seen best by most observers against a bright background such as the day-snow background. The brightest of four blank signs (i.e., without letters or geometric symbols) also is seen best against a dark night background most frequently. Adding large, bright letters and symbols to the simulated signs introduced a third influence on visibility or attention value, which depended on letter-to-sign brightness. Constant-brightness letters were found to have the effect of increasing brightness ratio as the simulated signs became darker, and this enhanced the attention value of the darker signs. Higher letter-to-sign brightness, therefore, opposed the effect of greater sign brightness against night backgrounds and added to the effect of a dark sign against a bright day background. By reducing letter brightness along with sign brightness, the letter-to-sign brightness effect on visibility was reduced.

These findings suggest that silhouette seeing is of importance for visibility or attention value where signs are seen against a bright background. The final two experiments in the series by Forbes, et al. (*170, 172*), report on color and brightness factors in traffic sign visibility.

The first experiment reported on in this paper concerned the effect of seeing four simulated green signs as used in previous experiments against three colored backgrounds. The background colors used were: (a) dark green trees, (b) a yellow-brown hill, (c) a blue-grey cliff. The signs used were the blank signs of four levels of brightness. It was found that the brightest sign was seen best against the green trees, the darkest against the yellow-brown hill.

Another experiment reported on investigated the effects of seven different colors of simulated signs seen against four different colored backgrounds (dark green trees, yellow-brown hill, blue-grey cliff, and day-snow scenes). The sign colors were black, dark green (with 30 percent overlay), blue, a saturated green, a brilliant red, yellow, and white. It was found that when the colors were arranged in a general order of brightness, the brighter colors were seen best more frequently. The average percent seen best increased nearly linearly with the log of brightness of the simulated sign, as might be expected of the different contrast against the four backgrounds of the seven colors averaged out. The exceptions were red and yellow and black signs, where hue contrast apparently added to the effective brightness contrast and modified the result. The authors point out that this was especially noticeable for the red, which was a brilliant, slightly bluish red contrasting well with the four backgrounds when projected in a laboratory. The final experiment reported on in this paper was a full-scale outdoor study used as a check on the laboratory data. In this study, each subject rode in a car over a standardized course and viewed regular street and highway signs against backgrounds of sky, trees, grass, country, bridges, buildings, and other city backgrounds and competing signs. The subject's task was to call out each sign as he noticed it, indicating color and location, and to push one of two buttons to indicate whether it was an advertising sign or a highway sign. In the field situation, it was found that most signs were reported well beyond the legibility distance of their largest legend. Further, when large overhead multiple installations were viewed with a sudden exposure, an advantage was shown for the left-most sign in daylight and the sign straight ahead under night conditions.

The authors present a mathematical model that gives the best fit for the laboratory results. They also provide suggested procedures for use by traffic engineers in predicting sign visibility.

It is obvious from all of the studies reviewed thus far that knowledge of the brightness reflectivity of any given delineation treatment does not provide the engineer with enough data to make decisions solely on that basis. There is sufficient evidence to indicate that the background against which any given treatment must be used must also be considered in deciding what treatment to use or what specific product to use. This, unfortunately, implies that either the situations and conditions for use have to be viewed rather intensively or that the engineer must make trade-offs and select the level of brightness that will give the best over-all performance. However, if the problem is one of night delineation, all the results indicate that the brightest treatment should be the most adequate. However, there is danger in making this as a general statement, in that at some point brightness becomes a glare problem to the driver. With respect to a treatment such as post delineators (which are relatively small in size) the point at which glare would become a problem has not yet been determined accurately. However, in situations where post delineators are relatively closely spaced, the continuous input, even though each individual stimulus is small, may result in a glare-like phenomenon for the driver. With respect to paint lines or pavement markings, it is unlikely that a level of brightness reaching the glare stage could ever be achieved—at least with the current types of treatment and the angle of incidence of light.

If the problem is one that requires use of color, another factor must be considered—the changes in perception induced by color. A study by Jones (*117*) shows that if color coding is to be used no more than eight optimally spaced stimuli should be used. He points out that color coding does not appear to be suited for situations that demand rapid and precise identification, but is extremely useful in decreasing times with locate-type tasks—something that is frequently required of the driver and for which current delineation treatments are used.

Smith and Thomas (*204*) found, in comparing shape coding and color coding, that color coding dominated in visual separability. This result argues for use of a color code as opposed to some of the current geometric codes being used. Mount, et al. (*158*), designed a field study to provide information as to the effect of color differences on the perception of relative distance in outdoor viewing situations. It was found that judgments of distance depend on the difference in brightness of the two standards, on the relative brightness differences of the comparison stimuli, and on the differences between the hue and its grey complement. The form of the dependencies in each case was found to be such that stimuli that contrasted most with the background were seen in front of stimuli that contrasted with the background relatively less. Thus, care must be taken in the colors used in terms of a background and foreground relationship if those colors are to be used as any kind of warning codes that require judgments of distance by the driver.

Visual Effects on Driver Judgment

The driver operates on the visual cues he perceives, and controls his vehicle accordingly. These control functions depend on certain judgments, or, as Michaels (*118*) has referred to them, "solutions to guidance equations." The key terms in these equations are time/distance relationships, which are based on perception of relative position, movement, and higher order derivatives such as velocity and acceleration. As defined by Schmidt (*149*), perception of motion is the ability to perceive a change in location of objects in time, and is actually a special case of direction and distance perception. He points out that it is possible to specify movement in terms of speed (distance traveled/unit time) or by the minimum displacement required to perceive motion. The minimum perceptible speed is given as 1 min to 2 min of arc per second (if reference objects are present). If, as in the dark, there are no reference points, this value increases to 15 min to 30 min of arc per second. In terms of displacement, the threshold without reference objects is roughly four times as great as it is with a reference point. There are, for the driver, a number of types of movement to be perceived and estimated—crossing, approach/receding, and own vehicle.

Salvatore (*147, 148*) has studied the problem of visual estimation of own vehicle speed. An observer riding in a car was asked to make estimates of speed when viewing the visual field centrally or peripherally through a special apparatus that controlled both field of view and exposure time. Other potential cues (auditory and acceleration/deceleration) were controlled. Results showed that peripheral cues lead to higher but generally more accurate estimates at all three speeds tested (20, 40, and 60 mph). For estimates from central viewing the absolute error increased with increasing speed. Increasing acceleration also increases error in all estimates. One obvious extension of these results to night driving conditions that further complicates that problem is the dependence on the less accurate foveal estimate due to reduced illumination of the periphery.

Another complex judgment the driver has to make has to do with the relative speeds involved in headway maintenance. The lead car changes relative position along the visual axis and changes in the retinal image tend to be minimal, resulting in higher thresholds of detection than if the movement were in the fronto-parallel plane. Braunstein and Laughery (*124*) and Hoffmann (*135*) have considered this problem in terms of elapsed time before an acceleration or deceleration by the lead vehicle is detected. The former effort was an experimental situation where the observer in the following vehicle on a four-lane, divided, limited-access highway viewed a lead vehicle that was operated such that two rates of velocity change and two inter-vehicle separations were systematically presented. The observer indicated when he detected a change and the direction of change. As expected, the results showed detection time increased with increased inter-vehicle separation and decreased in the higher rate change condition. Hoffman, employing a dimensional analysis, derived mathematical expressions to describe this situation. The expressions agreed well with the earlier experimental work, which showed that detection time varies as the square root of separation and as the inverse of the square root of lead vehicle acceleration rate.

Perception of distance is another important dimension of the driver's estimation or judgment problem. The initial perception of distance is a function of "depth cues," which fall into two categories—the solely binocular cues and the learned monocular cues. Stereopsis, or binocular depth, which is produced by the separation of the eyes, permits the recognition of relative distance and is much more effective in near vision, contributing little beyond 500 ft (*112*). Stereopsis is, like other visual functions, impaired by lowered illumination and short exposure times (*149*). This is unfortunate for the night driver, as many monocular cues are missing because of field restrictions and stereopsis is the dominant factor in space perception (*112*).

Monocular cues for depth or relative distance include relative size, position with respect to the horizon, overlay, brightness, contrast, and relative movement (*112*). Of these, the one that has received the most experimental attention is size; in particular, the influence of the size of familiar objects. A large number of laboratory studies (e.g., *157, 166, 167, 173, 174, 175, 184*) have been conducted regarding the "size-distance" hypotheses (for survey of earlier work see *156*). Of basic concern has been the relationship between retinal image size and perceived distance. In many cases enlarged or reduced views of familiar objects have been used to create a disparity between actual size of the retinal image and "perceived size." In general, the findings of these studies indicate that where retinal and familiarity cues are in conflict, those based on familiarity will be accepted. Also noted by many investigators was a substantial amount of individual difference in both relative and absolute distance judgment.

The passing situation, which involves oncoming traffic, combines both velocity and distance judgment and size cues from familiar objects (autos). This situation has been systematically investigated as a perceptual/judgment problem. Bjorkman (*113*) looked at the problem in terms of predictive judgments in a situation involving only the oncoming car. (No lead vehicle was present in the observer's field.) The subject/observer was asked to estimate the point at which the car in which he was riding would meet an oncoming car. Separation at time of judgment and closing rate were systematically varied on a closed course (airfield runway). Throughout the range of distances and velocities, accuracy of meeting point estimation was low for both experienced (drivers) and inexperienced observers. Judgments were least accurate with greatest disparity in vehicle velocities, most accurate with equal velocities (regardless of absolute values). The over-all average error approached 33 meters.

Hemstra and Jones (*134*) conducted a similar test including a lead vehicle (driven at 60 mph) and required the subject/drivers to indicate the last possible instant they could safely initiate a pass. The 19 subjects were as likely to underestimate as to overestimate the available clearance (no passes were actually performed, needless to say) and the conclusion drawn from the data was that most drivers are not capable of judging available clearance within a reasonable degree of accuracy.

Mast and Gordon (*141*) had drivers using familiar and unfamiliar cars make estimates of passing distance required at 18, 30, and 50 mph (no oncoming traffic present) and compared the estimates to the subjects' own performance. Again it was found, in general, that the estimates tend to be inaccurate—increasingly so at higher speeds.

In summary, it seems fair to say that judgments based on visual data regarding movement or distance tend to be less accurate than is desirable. Furthermore, the development of aids to perception and judgment that could be incorporated into the situation would be a potentially worthwhile endeavor. Preliminary indications are that certain delineation treatments might be of some assistance in providing known familiar references, thereby improving distance judgment and lowering the threshold for the detection of relative motion.

INFORMATION PROCESSING

The previous section deals primarily with factors related to the sensing aspects of information input. This section extends that review to include temporal, uncertainty, and content aspects of information input and their effects on information processing and performance. The purpose of reviewing this literature was to attempt to arrive at a set of basic guidelines that could be applied to the design of delineation systems. Knowledge of the basic factors that have been shown to influence performance, and specification of the direction and extent of their influence, would permit the derivation of such ground rules. It will be noted that the great majority of the studies comprising this review were accomplished in rather restrictive laboratory settings. This is an unfortunate but inevitable consequence of the requirement for precise specification of the information input variables. This requirement, in turn, stems from the fact that information processing abilities must be inferred rather than directly observed; we can't look inside a man's head. Field studies that would be directly relevant to the driving task are therefore not typically attempted due to the obvious difficulties in systematically controlling the input. It is for this reason that the word "guideline" was used previously rather than the word "principles." An additional benefit derived from the results of this review was the establishment of one of the bases for the rational evaluation of delineation systems, treatments, and/or techniques.

Before proceeding into a detailed review of the studies that have been done regarding man's information processing ability, some general statements about the measurement of these abilities are in order. First, as previously noted, information processing itself cannot be directly observed. One can only quantify inputs and observe responses made as a function of these inputs. From these observations, one infers that the time required to respond and the response accuracy indicate processing time and accuracy. However, little is known regarding the specific nature of the information channel of man. As is pointed out by Quastler (*285*), this channel is poorly defined, is poorly controlled, and has an enormous range of inputs and outputs. He points out further that although quantity can be specified there is no way to precisely describe input quality in more than the highly restrictive sense. This results from the great variation among individuals and the fact that input quality is a complex function of experience, education, and a number of other factors. It follows then, that to the degree to which input quality (as opposed to output quantity) affects man's processing capabilities, the assessment cannot be accomplished with any great degree of accuracy.

Quastler and his associates at the Control Systems Laboratory, University of Illinois, did a comprehensive series of studies on human performance and information transmission (*210, 211, 270, 286, 296*). The primary purpose of one of the early studies was to establish the maximum human information transmission rate (*286*). Other investigations in this series attempted to study the processes and factors that accounted for over-all capacity. It was found that performance of well-trained individuals on sequential tasks resulted in a transmission rate of 20 to 30 bits per second; that is, 20 to 30 binary decisions per second. It will be noted that if transmission is plotted on the same scale as information input, the resultant curve begins as a straight line rising at slightly less than a 45° angle, turns smoothly into a plateau, and declines again, the slope of the inclination being dictated by individual differences in reaction to the stress involved. The maximum value of this curve is the peak transmission rate associated with the particular input rate being investigated. With complex activities, however, this 20 to 30 bits per second rate is never achieved (see, for example, *230, 234, 291*). Obviously, the driving task must be rated as a complex activity and consequently high rates of transmission as obtained in the laboratory cannot be expected.

Quastler (*285*), in reviewing many of the studies from the Control Systems Laboratory, has provided a descriptive catalog of the more global factors that have been found to limit human capabilities to transmit information, as follows:

1. Processing speed.—Employing a definition of information processing as a sequence of discrete decisions, it has been established that there is a limit to the speed at which these individual acts can be performed. As Quastler points out, this speed is independent of the information content of a single act unless the content exceeds the capacity of the channel or is so complex as to create stress.
2. Span for simultaneous activities.—When dealing with conscious information processing it has been shown that a high rate of processing on one activity effectively blocks the accomplishment of other informational activity.
3. Information content per unit.—The number of different kinds of information contained in a unit has been shown to limit performance. This factor has been variously identified as Logan content (after MacKay, *260*), complexity, numerosity, dimensionality, or, following Miller (*199*), "span of perceptual dimensionality" (for simultaneous information), "span of immediate memory" (for sequential information). The underlying concept for all these terms is the same; a given amount of information may be structured into units in various ways, and performance effectiveness will vary as a function of this structure.
4. Amounts of information per stimulus dimension.—This has been called by Garner and Hake (*236*) "the span of absolute judgment" and involves the fact that different information may be conveyed by different aspects of a stimulus, such as color, shape, or symbol, or via more than one sense modality simultaneously. Performance effectiveness will vary as a function of this type of task complexity.
5. Information organization and/or filtering.—If the informational challenge threatens to equal or exceed man's processing capabilities, this difficulty may be overcome by reorganizing or recoding the information. In effect, this factor, which operates to increase over-all capacity, is also a limit when the recoding must be done at a time of information stress (i.e., overload) because it cannot then be done effectively. As Quastler points out, when man is overtaxed by the task, he can reorganize or recode only up to a point, at which time he switches to random sampling of the input and finally to complete confusion.

To summarize, the five factors that have thus far been found to limit human information transmission are (1) processing speed, (2) span for simultaneous activities, (3) task dimensionality or Logan content, (4) amount of information per stimulus dimension, and (5) filtering and recoding of information. Succeeding sections in this review present data from individual studies that show, in more specific detail, the degree to which these factors have an effect on man's information processing abilities.

Temporal Factors

It is a well-documented fact that as information challenge (high stimulus presentation rate) increases, errors become increasingly frequent until finally very heavy challenges lead to a breakdown of transmission. Quastler (*285*) uses the term "confusion effect" to describe the breakdown point, at which responding becomes random or ceases entirely. Different kinds of tasks and activities produce the confusion effect at different speeds. Load, which can be defined as the number of alternative stimuli and/or the complexity of a stimulus, also produces the confusion effect. It is not possible to state with any degree of confidence that the confusion effect will be exhibited when the stimulus rate exceeds a certain number of stimuli per unit time or that it will occur when a certain level of complexity is reached, nor can one make general statements about the related increase in number of errors or the slowing of response time as a function of either rate or load. The rate at which stimuli can be handled is dependent on many factors, some of which, as discussed in succeeding sections, can be employed to mitigate some of the detrimental effects of high stimulus input rates and/or high load conditions.

Studies to determine whether the rate of handling information in a forced paced serial task was a function of stimulus presentation rate, uncertainty * per stimulus, or the joint effects of these factors, have been done by Alluisi, Muller, and Fitts (*191, 206*) and McIntosh (*262*). In general, these studies indicated that handling rate was a function of both presentation rate and uncertainty. Increases in stimulus complexity produced many more omitted responses at high presentation rates than at lower rates. In other words, increasing the number of alternative stimuli and proportionately decreasing the rate of presentation improved over-all transmission performance.

In a series of studies concerned with stimulus speed-load stress, Conrad (*219, 220, 221, 222, 223*) had subjects perform a dial monitoring task in which the dials had continuously rotating pointers. All dials were in the field of view of the subjects and, as the pointers reached certain predefined dial markings, the subject's task was to respond with a key press. The stimulus events occurred in an irregular sequence, because the dials moved at different speeds. Conrad analyzed performance as a function of number of dials, speed of pointer movement, and the resulting changes in the temporal structure of sequential events.

In the first experiment, Conrad (*220*) was interested in the manner in which performance deteriorated as the signal frequency was increased. He found that, whereas response latency did not change, omissions increased in a positively accelerated manner from almost none at 40 signals per minute to 80 omissions per minute at the 160-per-minute signal frequency. Analysis of the omissions showed that the more closely a signal followed the response made to a preceding signal, the more likely it was to be missed.

* *Uncertainty* as used throughout this review refers to the predictability of a stimulus or stimulus sequence. That is, stimuli that are highly predictable have low uncertainty, and vice versa. Uncertainty is typically some function of the sequence in which stimuli are presented.

This effect became more apparent as average signal speed was increased.

Since, as average signal speed is increased, both signals and responses occur more frequently, one would intuitively attribute the negative effect of speed to an increased number of events (i.e., more signals and responses close in time to each individual signal as it is presented), a summation effect. Conrad, in his analysis, did not, however, find this to be true. He found it was the stimulus/response events occurring in close proximity to any individual signal that increased the probability that the signal would be missed. Other events in the over-all sequence had little effect on that signal. From this he concluded that an environmental stress, which is independent of changes in the over-all average temporal conditions but is related to the over-all time shortage associated with individual signals, is created as speed is increased. This he termed "speed stress" and suggested that it, along with the frequency of occurrence of short response-stimulus intervals in the sequence, was the major cause of response omissions. Although the signal rates for discreet stimulus input used in this study may be higher than those that would be found in a driving situation, the fact that subjects showed a decrement apparently because of the over-all time shortage (speed stress) is certainly relevant.

In another of the studies in this series (*219*), Conrad varied signal presentation rates over a wider range. The results of this study showed that slow signal presentation speeds tended to cause early responses, whereas fast presentation rates caused late responses. These changes occurred, however, without affecting the over-all temporal accuracy of the response (i.e., the response that was made occurred in the appropriate order). Although the early response problem is only of academic interest, the late response problem has relevance in that late responses in a driving situation can be correlated with accidents and/or erratic maneuvers.

Mackworth and Mackworth (*265*) did an experiment in which they correlated frequency of errors resulting from increased speed with the degree of temporal overlap among signals in a multiple-channel display. The number of spatial positions (i.e., stimulus alternatives or "load") was also varied while speed of decisions was held constant. More than the single-channel studies, this kind of a display situation is closely related to the driving task in that the driver must simultaneously monitor other traffic, signs related to delineation, guide signs, and markings. The authors found that errors of omission and commission increased as a positively accelerated function of speed of stimulus presentation and as a linear function of load. They state that the linear relationship between error and load could be attributed to, among other things, increased redundancy, increased sequencing difficulty under peak stress, and increased demands for eye movements. All of these factors could be operating in certain highway situations and the same types of error functions could be expected.

To determine with more precision the effective variable in this information load factor, Conrad (*222*) did a study in which load was varied between 4 and 12 input sources at a mean signal speed of 25 per minute. The measure of performance was number and duration of failures to respond. The data were analyzed on the basis of temporal bunching of signals (termed "crisis factor") and the failure of the subject to determine the correct ordering of stimulus events (termed a "disorder factor"). Neither crisis nor disorder occurred frequently enough to fully account for the observed performance decrement. Frequencies of disorders did, however, relate to increases in response failures; i.e., as the number of response failures or omissions increased, so did the number of occasions (per unit time) when the subject made responses in the wrong order. Furthermore, as load was increased these disorders occurred with increasingly longer mean intersignal intervals. In other words, at low load levels, disorders occurred only when signals in the sequence were close together; as load increased, disorders began to occur even when signals were farther apart in time. An additional finding from the analysis indicated that the probability that a given response (to a particular stimulus) would occur was increased when the time interval between the preceding event and that stimulus increased.

Matheny (*261*) obtained data that support the fact that neither number of different kinds of stimuli nor variations in input speed can be considered independently when determining the effects of stress on performance. It was found, however, that when signal frequency was fairly uniform many more different kinds of stimuli could be handled at one time.

In all of the studies reviewed thus far, the experimenter rather than the subject had control over the signal input rate. Because in the driving situation the driver can in part control the input rate by varying his speed, a number of studies in which the operator has control over the rate are relevant. There is evidence that in forced paced tasks that continue for an extended period, the average amount of information processed will usually be greater than when the operator can control the rate of input (*127*). However, it is clear that there are also disadvantages of enforcing a pace. Conrad used his multiple input task in studies in which the operator could control signal speed (*223*) and signal load (*221*). In both studies the instructions to the subjects were to optimize over-all performance; scoring was done on the basis of both speed and accuracy of response. In the first study (*223*), in which the subject controlled the rate of signal occurrence over a fixed number of input sources, it was found that performance improved as a function of the manner in which subjects changed the distribution of signals over a given time interval; i.e., as the signal distribution became more regular, performance improved. In the second study (*221*) load was systematically varied by increasing the number of relevant input sources and it was found that, as load was increased, subjects chose to maintain a constant over-all speed of signal occurrence, rather than to adjust the intervals to meet the new load demands. This resulted in performance decrement associated with increasing loads. This indicates that, as in the case of speed effects, load per se is responsible for considerable decrement in performance. This factor is termed "load stress" by Conrad. It should be noted that this study provides further evidence for the occurrence of load effects that are partially independent of the time interval between the preceding event and a given signal. Increasing the over-all amount of relevant information has also been found to degrade performance on information extraction and assimilation tasks unless the information is appropriately coded (*299*).

In addition to speed and load stress, both of which are related to stimulus events, there is also a response-related stress known as "pacing stress." This is where the stress is perpetuated, not by rate of stimulus, but by the speed with which the response must be made, independent of some stimulus contingency. In a study in which response speed requirements were varied, Slack (*294*) used a tracking task and found that at higher response speeds there was more variation in response and also the range effect (tendency to overshoot small inputs and undershoot large inputs in a stimulus series) was more pronounced. At low speeds the range effect decreased. McKinney, et al. (*263*), varied the speed of response required of subjects in a problem-solving task and found that as higher response speeds were required, the subjects attempted more problems and made more errors. He found, as did Slack, that when subjects were stressed by the response speed requirements there was a greater variability in performance.

The studies thus far reviewed indicate that many factors relating to both stimulus and response contingencies may produce a form of "task induced" stress that is detrimental to performance. However, except at extreme levels, performance decrement can often be reduced or alleviated by manipulating an interacting variable. For example, the detrimental effects of high stimulus load can be reduced by lowering the stimulus presentation rate (or, in some cases, by reducing the response time requirement). As will be seen, factors other than temporal factors (for example, redundancy or anticipatory information) can also be used to advantage in decreasing performance decrement in those situations where high input rates, high loads, or quick responses must be dealt with.

Additional data (such as cues, signals, or instructions) given to an operator preceding the stimulus (or set of stimuli) that relate to the occurrence of the stimuli or the associated response or set of responses are referred to as anticipatory information. In other words, it is warning information that tells the operator something about some future state of the stimulus/response complex. Anticipatory information may be partial or complete; therefore, it may be specifically about the stimulus, or about the response, or both. It is logical that if one can anticipate some required behavioral response and, therefore, be in a state of readiness, the response can be made both faster and with a higher degree of confidence.

Schmidt (*292*) has recently provided an excellent review of the role of anticipation and timing in human motor performance. It may be instructive to point out here that Poulton (*279, 280*) differentiates "receptor" and "perceptual" anticipation. As presented by Schmidt (*292*), *receptor anticipation* obtains in situations in which stimulus information is presented previous to the point at which a response is required, so that the subject can preview approaching events, thereby usually preventing a portion of the reaction time lag. That receptor anticipation effects are related to the ability of subjects to retain the previewed information is shown by Adams (*122*, reported in *292*) and supported by Poulton (*283*). *Perceptual anticipation* obtains in situations where the statistical structuring of stimulus events is such that the subject can learn the sequential dependencies and thereby predict an upcoming event (or stimulus) that requires a response. Within the category of perceptual anticipation, there are two subclasses—spatial and temporal. Spatial anticipation involves prediction of where a stimulus will occur; temporal, involves prediction of when it will occur.

Helson (*133*), Poulton (*279, 280*) and Leonard (*252*) have shown the value of perceptual anticipation in decreasing reaction times in several studies of sensorimotor skills. Data from studies by Mackworth and Mackworth (*264*), who used a search task, and Poulton (*281, 284*), who used a tracking task, provide further evidence for the value of anticipatory information across a wide range of tasks. The Leonard (*252*) and Mackworth and Mackworth (*264*) data suggest that anticipatory information to a tracker could provide at least a 20 percent reduction in the operator's processing time. As discussed by Schmidt (*292*), both Conrad (*224*) and Adams and Xhignesse (*205*) have recognized that anticipation and timing ability are independent of classical reaction time and have distinguished between reaction time (i.e., time from unanticipated stimulus to response) and response time (i.e., time from anticipated stimulus to response). Because with anticipation subjects may respond in advance of the relevant stimulus, it is possible for response time to be negative or zero.

A type of anticipatory information that does not fall under the previously discussed categories is the use of guidelines; these, in effect, put a restriction on the number of responses that should be considered in a particular situation. A series of studies in which the response restriction method was used (*256, 257, 258, 259*) indicate that, in using visual displays where the operator is required to perform a search task, the probability of stimulus detection and the subsequent correct response is enhanced by the presence of this type of anticipatory information.

Long, Henneman, and Reid (*256*) investigated the effect of response restriction on the complex perceptual task of locating and identifying a distorted geometrical figure that had been added to a 64-cell square matrix, already containing 16 other figures. The subjects locating responses were restricted in varying degrees by allowing them to view outlined areas of the matrix prior to the stimulus presentation, with the instruction that the stimulus would appear in the outlined area. The authors found that correct location responses were increased with greater response restriction. Using the same type of response restriction, Long and Lee (*258*) supported the finding that response uncertainty was reduced by location response restrictions. In another study (*257*) these same authors studied the effect of a second type of response restriction. Here the restriction was produced by allowing subjects to view groups of 1, 4, 8, or 16 figures, one of which was to be located when the test matrix was presented. With this type of restriction it was found that stimulus location was aided only when the degree of restriction was very pronounced.

Long, Reid, and Garvey (*259*) used ambiguous letter stimuli rather than geometrical figures to test the response restriction hypothesis. In order to provide differential response restriction, subjects were presented with lists of 11-, 8-, 6-, or 4-letter alternatives, one of which was the same as the distorted stimulus letter that had to be identified. This response restriction greatly increases correct identification of the ambiguous letters. The different effects that the same kind of anticipatory information has been shown to have on location responses (*257*) and identification responses (*259*) point out the value of selecting anticipatory information at the required level of specificity.

Although all the foregoing studies dealt with visual input of information, Broadbent (*217*) obtained data that show that the advantage of anticipatory information also operates when using auditory stimuli.

Finally, studies spanning a number of different types of tasks (e.g., *212, 244, 280, 282*) have demonstrated that the ability to anticipate improves with practice. Thus, the facilitative effects noted may be enhanced over time. Such enhancement in the highway situation, however, can be realized only to the degree that there is consistency in application of delineation treatments. Consistency will also determine the degree to which perceptual anticipation effects can be expected to operate.

Because in many cases the driving environment is such that stimulus uncertainty, information input rate, and load, etc., cannot be adjusted to be consistent with the driver's information processing abilities, the use of various types of anticipatory information is likely to contribute to better driver performance. Warning signs and sight distance "previews" are currently the only uses made of anticipatory information. The data reviewed suggest that other coding schemes involving the use of edge lines or post delineators might serve to improve driver performance in a variety of situations. For example, it would be possible to provide advance information regarding horizontal curves by varying the edge line pattern on the preceding tangent section.

Uncertainty Factors

Stimulus uncertainty refers to the predictability of a stimulus within a stimulus sequence. Although generally the larger the number of alternative stimuli in a set of inputs the greater the uncertainty, it should be noted that the stimuli can be statistically structured to manipulate uncertainty by varying the sequential dependencies or the probability of occurrence of individual stimuli within the set. As used in this review, stimuli that are highly predictable have low uncertainty, and vice versa. Response uncertainty, on the other hand, is related to the selection of a single response from a universe of possible responses. The larger the universe of responses that must be used for any given task, the larger is the response uncertainty. It should be noted that reduction of response uncertainty is one of the effects of practice; i.e., practice results in greater selectivity in what an operator attends to, elimination of unnecessary responses or response components, and an improvement or refinement of the necessary response components. In summary, it can be more simply stated that stimulus uncertainty refers to the lack of specific knowledge regarding which stimulus or stimulus events will occur next and response uncertainty refers to the lack of specific knowledge regarding which response is to be made next.

One of the more directly relevant effects of stimulus uncertainty is on identification thresholds for visual stimuli. A series of experiments by Krulee (*247*); Krulee, Podell, and Ranco (*248*); and Krulee and Weisz (*249*) showed that the distance at which stimuli can be identified is affected by the amount of uncertainty in the stimuli. By using a number of different stimuli it was found that threshold increases as a near linear function of the number of stimulus alternatives. The authors covered a range of from 4 to 35 alternative stimuli (*248, 249*). Another expected finding was that the actual amount of stimulus information was important; i.e., when subjects were led to believe that they would be required to attend to more alternatives than were actually being used, thresholds increased (*247, 248*). Further, when subjects were given no information as to the number of stimulus alternatives, thresholds were considerably higher than when they were informed. Another group of studies used reaction time as the primary dependent variable to study the effects of stimulus uncertainty (*153, 195, 201, 202, 215, 225, 231, 241, 243, 251, 266, 268, 269, 271, 287, 295*). Across a wide range of tasks and conditions, reaction time was found to be linearly related to stimulus uncertainty. This relationship seems to obtain whether uncertainty is varied by manipulating the number of alternative stimuli or by changing the statistical structure of the set.

Smith (*203*), in a review of choice reaction time studies, makes a tentative generalization that, for relatively unpracticed tasks in which there is not a 1:1 association between stimuli and responses, choice reaction time increases as the number of perceptually different stimuli increases. That is, the results seem to depend on the relation existing among those stimuli associated with the same response. This generalization is based on findings which indicate that, in tasks where the subject may filter out detailed differences between stimuli associated with the same response and attend to their common perceptual property, reaction time seems to be limited by the relevant perceptual properties (e.g., *225, 231, 268*). However, in tasks where the stimuli associated with the same response have no perceptual property in common, reaction time seems to be limited by the total number of different stimuli (e.g., *202, 225, 231*).

Smith, in his review, discusses the fact that the Rabbitt (*287*) and Pollack (*271*) studies indicated that the number of stimuli associated with any given response affected reaction time only when the number of alternatives was large (i.e., greater than six). Further, he points out that both experiments included conditions in which the stimuli associated with the same response were perceptually dissimilar and yet no increase in reaction time resulted from increasing the number of different stimuli per response. However, the fact that in Pollack's experiment all stimuli associated with the same response were members of the same category led Smith to suggest that the number of perceptually different choices does not affect reaction time if these choices are conceptually identical.

The studies discussed thus far have been examples of those that manipulated uncertainty by varying the number of stimulus alternatives. Another group of studies evaluated uncertainty produced by statistical structuring.

Henneman and Lloyd (*240*) studied the influence of the sequential order of stimulus events on performance in a card sorting task. They used varying orders of response uncertainty and recorded time and errors for sorting into three groupings. Error scores were found to be negligible and the time scores were found to decrease with practice. However, time scores increased significantly with increasing uncertainty of the order of the cards within the sorting decks.

Lloyd and Hodge made other studies using the same sort of task. However, in these experiments they added a retention variable to the stimulus uncertainty variable. In one study (*253*) they found that, in terms of the time required to complete a sequence of responses, proficiency decreased as either the retention requirement was imposed or as stimulus uncertainty was increased. In the second study (*254*), where they varied the degree of retention and, again, stimulus uncertainty, they found that performance was significantly decreased as more memory was required. However, contrary to their predictions and the results of previous studies, performance was not systematically affected by the degree of sequential uncertainty. The authors suggest that the most likely explanation for this is that response uncertainty, rather than stimulus uncertainty, may have been inadvertently varied in the experiment. This same effect was found in another study in which stimulus similarity and degree of retention were varied along with stimulus uncertainty (*255*); however, the same explanation probably can apply to this result.

Sumby and Lloyd (*297*) designed an experiment to demonstrate that more than one type of event can be statistically structured in the sequential task and found that level of performance is influenced by which specific event is statistically structured. The stimuli in this study consisted of sequences of patterns, varying in form, number, size, and interval marking. The subjects' task was to compare the stimulus patterns presented with previously seen patterns that had to be recalled from memory. Two kinds of uncertainty were introduced into the stimulus sequences: (a) a statistical structuring of the specific stimulus characteristics of the successive patterns (termed concrete uncertainty), and (b) structuring of successive rational comparisons that the subject had to make, independent of the specific stimulus characteristics that conveyed the relations. The authors termed this latter type of uncertainty "abstract uncertainty." It was predicted that task performance would benefit more from the abstract structuring because it would enable the subject to predict the successive rational comparisons independent of his previously seen stimuli. It was found that error scores did not reveal differences in task performance between the two kinds of uncertainty. Response times, however, were significantly shorter under the condition of abstract structuring. Although this study provided further evidence for the beneficial effect of statistical structuring, the more significant point made was the importance of determining what events should be structured in order to enhance performance.

These studies indicate that the relationship between input information and response is not solely a function of the number of stimulus alternatives. The relative probability of occurrence of the various alternatives and the sequential dependencies of the alternatives must also be considered. Hyman (*243*) varied the contribution of these factors to the total information presented and found that each had a linear relationship to response time. Later studies by several authors (*194, 229, 250, 251*) supported that portion of Hyman's results indicating that faster responses were made to stimuli having a higher probability of occurrence.

The question of statistical structuring of stimulus sets has given rise to two recent papers by Kornblum (*197, 246*) in which he obtained data that lead to a rejection of the so-called "Information Hypothesis" that ". . . all other things being equal, equiinformation conditions give rise to equal over-all mean RT's; that is, RT is a function of average stimulus information" (*197*). Kornblum (*246*) states that in those studies in which information had been interpreted as a determinant of reaction time, information was usually confounded with the probability of non-repetition of a given stimulus. That is, in most of the studies that showed a linear relationship between reaction time and amount of information ". . . it can be shown that for a fixed number of signals, the sequences of signals on which the evidence for the Information Hypothesis is based were constructed in such a way that stimulus information increased simultaneously with the probability of nonrepetitions." Kornblum, in a study in which these variables were not confounded, found that when reaction times for repetitious and non-repetitious stimuli are analyzed separately, each appears to be a function of the conditional probability of the signal.

Alluisi, Muller, and Fitts (*191*) did a study, discussed earlier in another context, in which they sought to determine whether the rate of handling information in a forced paced serial task was a function of: (a) the rate of stimulus presentation; (b) the uncertainty per stimulus; (c) the joint effect of these (expressed as a rate of information presentation per se). As noted previously, an interaction of stimulus presentation rate with stimulus complexity (i.e., larger number of alternatives) was shown in the distribution of responses omitted. Of concern here, however, is the finding that the percentage of omitted responses was relatively unaffected by increases in stimulus uncertainty at the lower rates of stimulus presentation, but was markedly increased by increases in uncertainty at the higher rates of presentation.

In a later study (*206*), the same authors made an informational analysis of verbal and motor responses in a forced paced serial task and again found that increasing the number of alternative numerical stimuli and proportionately decreasing the rate of presentation led to an increase in the over-all rate of transmission. These studies indicate that increase in absolute information handling ability that results from increasing stimulus uncertainty is apparently achieved without an appreciable loss in the relative accuracy of responses. Similar results were obtained by Klemmer (*138*) and Pollack (*272, 273, 274, 275, 276*). The results of these studies, although interesting from the standpoint of man's information processing ability, appear to be of little practical value in that one is seldom interested in absolute information handling ability (i.e., the measure of information transmission used in these studies is an average measure and does not attend to errors). Generally, they show that the greater the input, the greater the output, up to the channel capacity of the individual subject.

Just as the driver is faced with many and diverse informational inputs, he is also faced with a relatively large response universe (e.g., responses related to continuous on-going adjustive control, directional changes, lane changes). In this kind of situation the driver must filter and classify many informational inputs for purposes of response selection. Further, as vehicle speeds increase due to highway and vehicle design improvements, the task of classification and response selection will have to be accomplished with commensurately greater speed. For these reasons, some knowledge of the effects of response uncertainty is also important.

In an experiment in which Krulee and Sinclair (*198*) varied response uncertainty, it was found that an increase in the number of response categories seemed to increase the informational load on the subject and decrease the speed with which the task could be performed. Another experiment, discussed in the same paper, demonstrated the importance of ensuring that the subject be "tuned" to the appropriate minimum set of response categories. It may be recalled that this same principle was evident with respect to stimulus uncertainty (e.g., *247* and *248*). Krulee and Sinclair also point out that it is reasonable to assume that one of the important functions of anticipatory or warning information is to permit the subject to adjust to a restricted set of categories, thereby reducing the informational requirements for selecting the appropriate behavioral response. In short, anticipatory information can act to reduce the potentially negative effects of high response uncertainty.

Hyman (*243*) described a relationship between response uncertainty and reaction time in an experiment in which both stimulus and response uncertainty were always equivalent. His data seemed to indicate that reducing stimulus and response uncertainty together may decrease reaction time no more than reducing response uncertainty alone. In other words, the detrimental effects of stimulus uncertainty may be negated if response uncertainty is low. Bricker (*216*) provides some support for the previously noted relationship between response and uncertainty and reaction time. When an association task was used while varying redundancy and response uncertainty, Bricker found that response uncertainty had no consistent effects on rate of learning but was related to reaction time as an increasing function. Morin and Forrin (*267*) also used an association task to evaluate the effects of response uncertainty and found an increase in reaction time. However, the authors point out that their procedure may have produced a confounding of the uncertainty variable by imposing a memory requirement that increased with increase in uncertainty.

It cannot be assumed on the basis of the foregoing evidence that increases in the response uncertainty will always produce performance decrements. The effects of response uncertainty have not been ascertained over a wide enough range of dependent variables for such a generalization. For example, in the case of a psycho-physical experiment, Ericksen and Hake (*227*) found that discrimination, as measured by information transmitted, remained constant as the stimulus and response categories equalled or exceeded the number of stimulus categories. However, there was a loss in discrimination when the number of response categories was fewer than the number of stimuli to be judged. This finding may be in part attributable to the anchor effects that characterize the absolute judgment method that was used.

It would appear that the primary detrimental effect of high response uncertainty is on reaction time as opposed to response accuracy. However, in terms of total performance, the data available suggest that response uncertainty may be as important as stimulus uncertainty in terms of its effects on human information processing.

Another factor, related to stimulus and response uncertainty, that has been shown to have an effect on man's information processing ability, is stimulus-response compatibility. This refers to the interaction effects of the nature and mode of the response medium. In general, the more compatible the stimulus with the response, the greater the rate of information processing. Fitts and Seeger (*193*) hypothesize that man's performance on a perceptual motor task should be most efficient when the task necessitates a minimum amount of information transformation (and coding and/or decoding). Minimum transformation obtains when the information generated by successive stimulus events is appropriate to the set of responses that must be made in the task, or, conversely, if the set of responses is appropriately matched to the stimulus source. Thus, the problem of coding is central to the topic of compatibility. The authors obtained data (*193*) supporting the aforementioned hypothesis and concluded that it is not permissible to assume that any particular set of stimuli or set of responses will provide a high rate of information transfer, but that it is the ensemble of stimulus response combinations that must be considered. A number of other studies (*206, 207, 213, 214, 232, 245*) show the facilitative effects of high stimulus-response compatibility. In the driving situation the left-turn arrow painted on the pavement is an example of a stimulus that is highly compatible with the response the driver must make.

Content Factors

The final two major factors that have been shown to affect man's information processing performance are information relevance and information redundancy. These two factors are differentiated from the other factors discussed in that the degree to which a given piece of information or stimulus is relevant or redundant is highly dependent on the individual who is using the information and is, therefore, not an intrinsic factor such as uncertainty and stimulus rate. The problem of relevance has considerable practical importance in considering the information processing aspects of the driving task. The driver with a predefined destination is looking only for those information inputs relevant to the control manuevers required for him to reach that destination. However, in most cases he is faced with a great deal more information than he needs.

Irrelevant or excess information acts to increase over-all search time (i.e., loads the visual channel), generally increases reaction time, and may also act to produce response competition. Goldstein, et al. (*237*), also found that complex vigilance is detrimentally affected by irrelevant information. Although the effects of irrelevant information are generally detrimental, they are not unequivocably so in that they appear to depend to a large degree on interaction with other factors.

A number of studies (*200, 226, 233, 238, 277, 278*) have shown that search time increases in near-linear fashion with increases in the amount of irrelevant information. In most of these studies, the subject was required to search display matrixes of various sizes and compositions and to locate a target dot somewhere in the matrix. Irrelevant information was in the form of either non-target dots or blank cells.

Hodge (*196*), in the study of complex visual discrimination, varied (a) number of irrelevant dimensions on the stimulus, (b) difficulty of the discrimination, and (c) the amount of practice on the task. He found not only that increasing amounts of irrelevant information had a detrimental influence on performance, but also that both the amount and nature of the irrelevant information were important. He also found some indication that practice might reduce the negative influence of irrelevant information. Mackworth and Mackworth (*200*), in another paper, state that practice assists only to a degree in alleviating the effects of irrelevant information. With respect to training, Gregg (*239*) found that when subjects were trained to respond to changes in one stimulus dimension, the presentation of irrelevant information via changes in a different dimension concurrent with the changes in the dimension on which the subject was trained produced performance decrement. Concerning specific causal factors related to performance decrement, Hodge's (*196*) study produced some evidence that suggests that the ability of irrelevant information to arouse competing responses is as important a factor as the amount of irrelevant material per se in determining performance.

Archer (*208*) varied relevant and irrelevant information on a pattern recognition task in which the patterns could be varied along six dimensions, each having two values. With the presentation of a stimulus pattern, the subject's task was to depress a response key for each relevant dimension. He found that although average time for response increased in a linear fashion as a function of the amount of relevant information presented, this measure was independent of the irrelevant information presented. These results are not consistent with the results of a more recent study by Rabbitt (*288*), which suggest that tasks that require subjects to ignore aspects of the stimulus within a dimension (i.e., as opposed to ignoring an entire dimension) show a more marked increase in difficulty with increasing amounts of irrelevant information. Several suggestions have been made as to why the irrelevant information had no effect on Archer's subjects. One factor that may be important is that the subjects were familiar with the relevant material but not familiar with the irrelevant, whereas in some of the other studies (e.g., *239*) the subjects were familiar with both relevant and irrelevant stimulus items. Another suggestion concerns the fact that irrelevant information in the Archer study was never relevant or essential to discrimination, thereby reducing the probability that it would ever contribute to competition among responses.

Hodge and Reid attempted to test the validity of the latter suggestion about Archer's findings. They used an identification task that was comparable to that used by Archer, but instead of having some information that was never relevant, they were concerned with the influence of information that was sometimes relevant to the task and at other times irrelevant. This is precisely the type of situation with which a driver is faced. Hodge and Reid asked three questions: (a) Is the amount of information that is sometimes relevant and at other times irrelevant a factor in impairing performance of the task? (b) Is the effect of this sometimes relevant, sometimes irrelevant, information related to the difficulty of the discriminations involved in the tasks? (c) Is the effect of this sometimes relevant information reduced by practice on the discrimination task?

In two experiments they found that the presence of sometimes relevant, sometimes irrelevant, information produced a higher performance decrement than did irrelevant information that was never relevant. Further, they found that increases in this sometimes relevant, sometimes irrelevant, information produce progressively greater performance decrement. They also found that practice in many cases produces a decline in the decrement. Concerning discrimination difficulty, they found that as difficulty increases with the always relevant information, the detrimental influence of sometimes relevant, sometimes irrelevant, information also increases. Another study by Reid, Hodge, and White (*290*) investigated the questions: (a) Do increases in the similarity between the relevant and irrelevant information cues present in visual stimulus patterns influence the performance on a complex identification task? (b) Does the effect of such similarity interact with the effect of increasing amounts of irrelevant information? In terms of both response latencies and errors, the degree of similarity between the relevant and irrelevant stimulus values was found to influence performance significantly. The interaction between similarity and amount of irrelevant information was also significant. Further, the impairing influence of irrelevant information decreased with practice on the task.

Two more general reasons why the effects of irrelevant information may not be detrimental to performance are provided by Senders (*293*) and Krulee and Sinclair (*198*). Senders had subjects read a number of dials presented in short exposures and found that reading time increased with the number of relevant dials that had to be read and was not influenced by those dials that did not have to be read (i.e., irrelevant dials). The author suggests, on the basis of these data, that in some situations there may be spatial factors involved in the effects of irrelevant information; i.e., when irrelevant stimuli appear in the single event they are harder to disregard than if they are separated spatially. Support for such a suggestion is provided by the data from the Krulee and Sinclair experiment, in which the author suggests that the complexity of the process of elimination of irrelevant information seems to depend on whether it was perceptually possible for a subject to minimize the information load of irrelevant messages by treating them as a single category of information. It would seem that one method of minimizing the perceptual load would, in fact, be the spatial separation suggested by Senders.

Related to the problem of information relevance is the problem of redundancy. Redundant information, as defined for the purpose of this review, refers to stimulus information that, in a given stimulus-response sequence, presents a recipient with no new information concerning a given response; or, as Turner, et al. (*298*), defined it, "as an alternative input which can be used to obtain a desired output as efficiently as some other input message." (Note that additional technical definitions of redundancy are used in the literature.) Evans (*228*), in fact, points out that differences in conceptualizations and measurement procedures present a confusing situation. For example, Garner (*235*) associates redundancy with increased complexity, whereas Attneave (*209*) and Hochberg and McAllister (*242*) relate it to simplification. Evans provides a synthesis that allows quantification of both kinds of redundancy under the same conceptualization. However, because his discussion and the research reported are limited to redundancy in patterns, no detailed discussion of the results is given here. He suggests, however, that theory based on an analogy between humans and a hardware communications channel may be too elusive to be useful.

The point at which redundant information becomes excess or irrelevant information is dependent entirely on the specific task and specific subject. In other words, it must be operationally defined as that point at which the redundant information no longer has utility.

Turner, Wallace, and Wessel (*298*) performed an experiment to find the effects of redundant information on accuracy, speed, and efficiency of task performance. In this study subjects were given 12 tasks, each consisting of a series of input messages, a single output message, and a series of rules for deriving a given output message from the group of input messages. To increase the generality of the results, all messages were expressed in abstract form. Performance was measured by (a) amount of time required for completion of the problem, (b) the number of successful and unsuccessful completions, and (c) the use of efficient or non-efficient solution methods. They varied the number of redundant messages from 0 to 3. An analysis of the results showed that increasing the number of redundant messages, up to 3, did not change the number of correct solutions. In fact, the exact effect of redundancy on the number of correct solutions depends on the difficulty of the problem. On the average, increasing amounts of redundant information increased processing time; but as the difficulty of the problem increased, the deleterious effects of redundancy on speed decreased.

This increase in reaction time apparently produced by redundancy was also observed by Bricker (*216*) in a paired-associate learning experiment. Here he found increases in reaction time with increases in the amount of redundant information. Rappaport (*242, 289*) obtained similar results for a visual discrimination task and suggests that redundancy in a relatively noise-free situation does not have much of a facilitating effect because it is, in fact, irrelevant information. However, as noise was added to the figures that had to be discriminated by the subjects, redundancy was shown to have a facilitating effect.

Fitts, Peterson, and Wolfe (*194*), in a series of three experiments using naming and pointing tasks, found that as redundancy increased, average reaction time to the frequent stimulus component decreased, whereas the less frequent components produced slower reaction times. The differences between the two were shown to be a linear function of redundancy. Earlier studies by Hyman (*243*) and Crossman (*225*) also showed the reduction in average reaction time in proportion to average redundancy at any given stimulus set size. It should be noted that the definition of redundancy used in these three studies relates to frequency of presentation of stimuli in a set where all possible sequences are not equally probable. For this reason, the same studies are discussed briefly under the topic of stimulus uncertainty.

In summary, redundant information can have a facilitative effect if the input situation involves high rates or loads; however, if the subject is not under an informational stress situation, redundant information may become irrelevant (or excess) and, thus, have the previously stated detrimental effects on processing performance.

Taken as a whole, the literature on human information processing indicates that factors such as high input rates, high informational loads, rapid response requirements, and high stimulus or response uncertainty produce performance decrements manifested in omitted responses and increased reaction times. However, these detrimental effects can often be alleviated or reduced by (1) providing the subject with warning cues or instructions that permit him to anticipate an upcoming stimulus or response event, or (2) careful and deliberate use of redundancy.

II. DRIVER DELINEATION REQUIREMENTS

It was the initial premise of this project that the "general objectives of delineation systems are easing the driving task and enhancing the safety of highway travel" and further that the "basic problem . . . is the definition of the driver's requirements (equaled to delineation purpose) and the concomitant development of effectiveness measures." In the process of translating these general notions into the actual conduct of the project, the problem of defining the driver task and isolating those aspects of the task that are susceptible to treatment via delineation became the central concern. A number of theoretical papers have undertaken to provide models of the driving task (*111, 115, 118, 120, 121, 130*) and the conceptualization employed here represents a selective synthesis of ideas drawn, in whole or in part, from these sources.

DRIVING AS A PERCEPTUAL TASK

Perhaps most basic to the over-all view of the driving task is the earliest of these writings, the 1938 paper by Gibson and Crooks (*130*), where they define a field of safe travel, a minimum safe stopping zone, and the ratio between the two. The fundamental stance taken by the authors is that the driving task is predominantly a perceptual one. They begin by assuming that the driver wishes to move through a terrain, or "field," from one place to another, the destination. In the course of this action obstacles are *seen* and must be avoided to prevent collisions. To summarize their assumptions they say: "Locomotion (driving) is therefore chiefly guided by vision and this guidance is given in terms of a path within the visual field . . . such that obstacles are avoided and the destination . . . [is] reached." This visual field is peculiar in a number of ways, but most particularly it is selective; i.e., elements that are important or influential with respect to locomotion tend to stand out and are attended to, while the remainder of the potential visual stimuli become background. The roadway is the most important part of this field and within the confines of the road lies an indefinite and changing area called the *field of safe travel*. This field is a composite of all the possible paths to the destination the car can take, at any given moment, without encountering an obstacle of any sort. It should be emphasized that this field is constantly changing as the car moves through space, because it is defined in reference to the car and its extent in any direction as a function of the type and location of relevant obstacles. The fluctuation of the field requires of the driver a constant process of perceptual reorganization that varies in complexity (in terms of speed and number of factors) as a function of situation (in terms of geometry, traffic, etc.), and, further, the adequacy of this process is influenced by factors arising in the environment (darkness, etc.) and in the driver (acuity, experience, etc.)

It can be observed at this point that at some times the perception of a field of safe travel is a fairly easy task and at others it is complex. This observation forms the logical basis for the selective set of situation models employed later in specification of delineation requirements. Essentially, the view taken is that the less complex the situation, the easier the perceptual task, the less the driver needs the organizational aid provided by delineation, and, further, there is less utility associated with providing a model to cover that situation.

To return to Gibson and Crooks (*130*), the second concept introduced in their development, which is particularly germane to the current problem, is the notion of a minimum stopping zone. Although this zone is relatively easy to define objectively, given the vehicle velocity, the efficiency of the braking system, and the frictional coefficient relating tire and road, the authors point out that a driver's perception of the extent of the zone may or may not coincide with the objective reality. At any rate, the driver is presumed to operate such that the zone is kept at all times smaller than the field (at least perceptually). In those cases where the field suddenly contracts or where speed is increased such that the size of the zone approaches the size of the field, the driver is in a dangerous or emergency situation. Now, because it can be assumed that drivers would rarely, if ever, knowingly place themselves in such a position, it can further be assumed that a failure in perceptual organization of the field, or the zone, or both, is involved. In short, the driver's requirement is to perceive accurately all the actual and potential obstacles at any given instant and to know his and the vehicle's capability to come to a complete stop, given any combination of road, speed, and conditions. This grossly described and obviously impossible to maintain state must be at least approximated to achieve safe travel. In order to understand and apply this notion in any meaningful way it is necessary to define what factors limit the field of safe travel. The authors list the following: (1) natural boundaries, (2) inflexibility at higher speeds, (3) obstacles and their "clearance lines," (4) moving obstacles, (5) potential obstacles, (6) legal obstacles and legal taboos.

Of these, all have some potential relevance in the development of driver delineation requirements and therefore merit brief discussion here. Natural boundaries relate to physical and physiological limits and include visual acuity, illumination, environmental conditions, and road geometry as it affects sight distance. The second factor refers to the effects of centrifugal force in turns at high speed; a turn can be only so sharp without risk of a skid. In the third class, all obstacles are seen as having "clearance lines," a symbolic representation of the assumed effect or cost of a collision. For example, a steep bank or cliff is given more clearance than a shallow ditch; a large roadside boulder, more than a patch of tall weeds. Moving obstacles influence the perception of the field of safe travel not by where they are at the moment but rather by where they are expected to be; i.e., the driver makes a projection of path and speed as it relates to his own path and behaves accordingly. The fifth category—potential obstacles—is related to the driver's judgment and experience concerning what may happen to his field of safe travel as a function of objects and events not currently in his visual field; e.g., a child behind a parked car, or an oncoming car around a blind corner. The legal category covers the entire range of traffic control mechanisms, including signs, signals, markings, etc.

DECISION AND CONTROL FUNCTIONS

At this point it appears useful to leave Gibson and Crooks and to continue the development of this formulation as was done in a 1954 paper by Schlesinger and Safren (*121*). In expanding the previous work, they list five critical tasks of the driver, defined in slightly more operational terms, and go on to amplify the notion of perceptual organization as driver information processing. In referring to work by Gagne they list three critical perceptual skills: (1) sensing or observing, (2) identification, and (3) interpreting.

Sensing or observing refers to more than the simple capacity or acuity of the senses (although it is intuitively obvious that this provides the limiting cases). Within the normal range of function it would appear that the efficiency of the observational procedure is the determining factor and that, to improve driving behavior, improvement in search and scanning routines is indicated. This would serve to minimize the probability that a relevant stimulus may go unnoticed.

Identification, the first step in the processing of sensed or observed stimuli, involves classification into meaningful categories. These categories are seen by the authors as consisting of the various limitations of the field of safe travel mentioned earlier. This is, of course, not an exhaustive set of categories and must be expanded to include the positive as well as the negative aspects of the field and the attributes of and influences on the stopping zone as well.

Interpreting is the activity of translating the stimuli and their meaning into a decision, judgment, or estimate that will govern subsequent control actions. As such it is influenced by rules or strategies previously taught or developed by experience.

Although the foregoing is useful for an over-all conceptualization of the driving task and even though the tie-in with delineation is frequent and obvious, it soon becomes apparent that a more microscopic and potentially more objectively assessable breakdown is required in order to facilitate the development of driver delineation requirements in the context of specific situations. Recent applications of operations analysis techniques provide some useful guidance along these lines.

Platt (*120*) attempts to detail the fundamental parameters relating to traffic safety and to classify them. He begins with an over-all concept of traffic situations stemming from the wide variety of events that are presented to the driver. These events may or may not be related to driving, and they may or may not be observed. Decisions (mostly correct) are made on the basis of those events related to driving that are observed, and actions are governed by these decisions. To further clarify this view, it is translated into the terms of cognition as follows: events are stimuli; observations are made via the senses; perceptions are decisions; and actions are responses. Events are then catalogued as they relate to road structure, environment, stationary objects, moving vehicles, and inside the vehicle. (Note the close similarity to the limiting factors of Gibson and Crooks.) Driver observations are then tabulated in terms of 11 senses, with overwhelming importance reserved for vision. Catalogs of decisions and actions in much more general terms are also provided.

In Platt's original over-all analysis, and as he develops it in a later paper (*143*), the emphasis on events, in particular unobserved events and the factors that dispose the driver to miss or misperceive events, draws attention to the importance of making the driving task easier by simplifying the perceptual task. In the model, incorrect actions are seen as the "cause" of accidents and these incorrect actions arise from unobserved events and incorrect decisions. Inasmuch as it is plain that incorrect decisions are relatively rare, the missed observation becomes central. In relating events to observations a model is provided that details and interrelates the factors that screen the total possible observations and reduce the ratio of total relevant observations made of the total possible. It can be concluded from this development that as the total number of events to be observed increases the probability of failing to observe a particular critical event will also increase. From this it would follow that it is incumbent on those responsible for highway planning, design, and operation to provide aid for the driver that is designed to counteract this trend. Specifically, it should be possible through the use of delineation to enhance the probability that a particular critical event will be observed by improving its visibility and the time/distance factors relative to the driver's current position. Of course, such a strategy requires identification of the critical events involved in various specific situations; and, for this, both Platt's catalog and the field-of-safe-travel notion are highly useful.

A final link in the chain of conceptual development regarding the driver task stems from those workers who have focused on the driver as a decision maker and feedback loop control component in the driver-vehicle-roadway system. This basic approach can be carried out in various ways. Two of the more useful and straightforward are represented by Cumming (*115*), who focuses on the driver skills involved, and Algea (*111*), whose orientation is toward operation of the "control model" in specific situations.

Cumming's point of view is typified by one of his introductory paragraphs where he writes:

> A study of some of the human characteristics involved in this skill (driving) can be helpful to engineers responsible for designing the vehicles, the road and traffic systems, and the rules within which the driver operates. Clearly these must be matched to the man if this complex man-machine system is to function efficiently and safely. [It is] imperative that account is taken of the full range of human characteristics likely to be found in the [driving] community.

The driver is seen as having three main functions: perception, decision making, and control. These functions interact in a highly complex manner in the performance of the over-all task (which includes lateral tracking, speed control, and obstacle avoidance). Performance quality is seen as a function of the human capability to gather information by sampling the many sources arrayed before him and to process this information appropriately for making timely decisions. This decision-making process can be directly influenced in a number of ways, including the rate of presentation, the number of possible actions, use of positive or negative information, prior warning, and the capacity of the short-term memory. Finally, it is possible to translate what is known regarding these factors into principles for traffic system design and thus ensure the appropriate matching of the human capacities with the characteristics of the system components.

Algea (*111*), who takes a more situationally oriented approach, also views the driver as the control unit of the driver-vehicle feedback model. He begins with an analysis of the single driver-vehicle model in which he postulates a reference input variable of "desired velocity" and a controlled output variable of "actual velocity." A major corollary of this is that the driver will attempt to maintain the higher-order derivatives of the velocity at zero. In order to complete the model by providing for change in behavior over time he adds the notion of "adaptation," defined as a "change in the sensitivity of a sense organ due to stimulation or lack of stimulation." The model is then extended to include overtaking, following, passing, and variations of each, with the emphasis on the interactions between driver-vehicle units. It is apparent that this line of development is different from all others reviewed here, primarily because it focuses on the output side and attends little to how the driver selects cues, processes them, and acts on them. It is for this reason that this model is included here, because it provides the needed connections between the driver and the situation. It clarifies the fact that the driver does not behave in isolation and relates the behavior of drivers to over-all traffic movement and to the concepts of traffic flow, all of which are important dimensions of the real world that can easily be overlooked when focusing on the individual driver and his powers of perception, decision, and control.

DRIVER FUNCTIONS AND THE ROADWAY SITUATION

To extend the foregoing observation one step further, for the purposes of this project, it is essential that the connections between the driver's functioning and the roadway situation be made operationally explicit. It is necessary that point by point correspondence be established between the road situation and the action required of the driver-vehicle unit; between these actions and the mental process of judgment, estimation, or decision that guided them; between these decisions and the observations or perceptions on which they were based; and, finally, between these perceptions and the physical characteristics and location of the stimuli that elicited them. By completely specifying these relationships, it is possible to anchor the input both to and from the driver-vehicle unit in such a way as to permit specification of the necessary and sufficient stimuli for negotiating any given maneuver or highway geometry. Furthermore, this specification will permit the development of the requisite time/distance relationships that in turn will provide specific objective reference points in the physical situation for the subjective and unobservable phenomena of driver perception and decision making. Although it would be difficult (perhaps even impossible) to specify exhaustively all of the foregoing relationships, it is feasible to attempt to delimit the problem and focus on delineation and related aspects. This can be illustrated in the form of the following questions:

1. Regarding the road situation and actions—at what point(s) must an action or definable part thereof be complete? (e.g., the vehicle must come to a complete stop at or prior to the stopline).
2. Regarding actions and decisions—if an action takes a given time (or distance) to accomplish, what is the latest point in time or space that the decision must be made? (e.g., at 60 mph a comfortable deceleration requires 8 to 10 sec).
3. Regarding decisions and perceptions—if a timely decision is to be made correctly with a high degree of reliability, at what time or at what point must the required observations be made? (e.g., decision time for a two-choice alternative (stop/go) is 0.3 sec, and at 60 mph 0.3 sec = 26 ft).
4. Regarding perceptions and stimuli—if certain perceptions (observations) are required, what stimuli have a high probability of detection and sufficient information value to assure that they will be seen and understood at an appropriate point in time and space? (e.g., to be maximally detectable the stimuli should be within 10° of center in the visual field; must have a maximum contrast with the background; must be of sufficient size; and must have sufficient brightness/reflectivity to be seen under low illumination and at sufficient distance, etc.)

As can be seen from the number of factors involved and their inherent complexity, answering these types of questions systematically over a wide range of situations and environments is no easy matter. It is for this reason that a proven procedure known as Information Decision Action (IDA) analysis was employed to provide the necessary systematization. In addition, the IDA has a number of useful side benefits because in the process of applying it both the types and locations of evaluation data collection are suggested. Although initially essential, the key issue is not, in the final analysis, the systematic mapping of the IDA sequence but the methods of assessing effectiveness that are critical. The translation of driver requirements into delineation requirements implies not only the identification of what information the driver needs but also the relative effectiveness of the alternative methods of presentation. It is at this point that the second half of the problem—effectiveness criteria—must be faced.

CRITERIA OF EFFECTIVENESS

At first glance it may appear strange that the development of criteria of effectiveness should be a problem, because quite clearly the ultimate payoff for highway improvements is in accident reduction. It is also obvious that many delineation treatments can have direct effects in terms of traffic flow. Improvements in this area also comprise a definable payoff. Why not then employ either or both of these factors as effectiveness criteria for delineation?

Perhaps the most compelling and often stated argument against direct use of accident records is that expressed by Perkins and Harris (*377*), when they say: "Analysis of traffic accident records . . . showed that the reported numbers of any particular type of accident were not large enough for adequate analysis." In short, for research purposes there are not enough accidents! Another side of this point is exposed when the same authors decry the necessity of "waiting for an accident history to evolve"—the time interval between accidents is too long for the researcher to wait for them to happen.

In addition to the preceding overstated but nonetheless real drawbacks to the use of accident statistics and/or accident observations, some more subtle but equally pervasive deficiencies exist. The first is a systematic fault highlighted by Michaels (*118*) and supported in copious example in two papers by Goldstein (*131, 132*). Michaels notes that attempts to associate accident occurrence with any single factor (the specific defect approach) have met with a spectacular lack of success. The Goldstein papers empirically substantiate this claim by reviewing past research and reporting correlations between a wide variety of variables and various indices of traffic safety. The overwhelming impression gained from studying these reviews is that even when the correlations are statistically different from zero they are so small as to be of little practical value, only rarely accounting for more than 20 percent of the variance. The second subtle deficiency alluded to previously is in the reliability and validity of accident records. Not only is it an acknowledged fact that eyewitnesses are often wrong about what they report they saw, but also many accidents are reported only by parties involved (with obvious bias) or in an after-the-fact fashion by an investigating officer. Additionally, report formats are, of necessity, general in nature and often categorize events and locations in a gross fashion. As a direct consequence, any derived index is most likely to be insensitive to small changes in the total situation; e.g., changes in delineation treatment. Finally, supporting data of vital interest to the researcher are often virtually unavailable; as, for example, in the case of a spot-improved location where accurate descriptions of the before condition are difficult to obtain. Other relevant data regarding volume, traffic composition, enforcement, etc., are also difficult to obtain. In summary, it seems fair to say that the direct use of accident records as a criterion is inappropriate (if not impossible) in this case.

Traffic operations efficiency measures (such as travel time, delay, ADT) certainly do not have many of the problems associated with accident data, but for use as criteria of delineation effectiveness there are some important limitations on their usefulness. Perhaps the most damaging of these is a lack of sensitivity, in certain situations, to changes in delineation treatment. For example, how likely is it that changes in delineation treatment for horizontal curves of 5° or greater on a rural two-lane highway with an ADT of 600 vehicles will produce measureable changes in the throughput of a given road segment? This is not to say that these measures are always insensitive, because it is obvious that the delineation changes at intersections can plausibly be expected to be reflected in throughput measures. However, by their very nature these measures are more useful in some types of situations than in others. Another facet of this problem is the role played by over-all volume. Given two locations (e.g., a four-way signalized intersection) of identical geometry but differing greatly in volume, for the low-volume site throughput measures are not likely to be useful because they cannot vary enough to reliably reflect changes in treatment. (It might be noted at this point that this was of real concern in this project because the main emphasis was on rural roads and, in general, volumes at the study sites were low.)

Even after two of the originally most likely criteria are eliminated, the requirement for sensitive, reliable, and valid criteria of effectiveness still remains and other avenues must be explored to satisfy it. One possible source of alternatives is the literature surveyed in the state-of-the-art review. What measures have been used in the past to evaluate delineation treatments or similar peripheral modifications in the highway? Although there is a wide variety of answers to this question, in general there appear to be a limited number of basic types, of which vehicle dynamics, driver comfort, and near accidents are the most common.

The near accidents category can be further subdivided into erratic maneuvers and conflicts. Representative of the first of these subcategories is a study performed by the Michigan State Highway Department (*85*) where one of the measures employed was a count of erratic maneuvers. In the words of the authors:

> Extreme erratic maneuvers were recorded separately. In order to avoid any question of judgment regarding what constituted an erratic maneuver, it was decided that . . . any vehicle that made two lane changes within the study section would be so classified . . . this classification included any extreme movements such as stopping and backing up . . . radical movements across the gore and vehicles stopping . . . and then proceeding.

This wide latitude of classification gave way, in a later study reported by Conley and Roth (*3*), to a more specific operational definition of five different erratic maneuvers. Counts were maintained separately for each. An example of one such operationally defined erratic maneuver was: "Delayed exit—this is a vehicle that delays its exit long enough to drive across the painted gore or dirt." This same study, however, points up one of the problems with using this type of near accident measure—in 16 hours of observation at each of 14 locations for the "before" and again for the "after" condition only 834 erratic maneuvers of all types were observed (an average of only 2 per hour at each location). This is further complicated by the fact that when the total before/after, location × maneuver matrix (in which 2 locations were dropped due to low volume) is examined it shows 38 of the 60 cells with a frequency of 1 or less. In short, the data tend to be both scarce and spotty.

The other approach to the "near accident" category is reflected in the work of Perkins and Harris (*377*), who developed a conflict analysis for the evaluation of intersections. They define operationally 20 different objective criteria for traffic conflicts (or impending accident situations). As they describe it, ". . . essentially these traffic conflicts are defined by the occurrence of evasive actions, such as braking or weaving, . . . or a traffic violation." This method results in much higher frequency counts in shorter periods of observation and appears to be a sensitive indicator of certain types of effects, such as changes in regulatory signing. In addition, an external analysis by the current authors employing the tabular data reported by Perkins and Harris resulted in a Spearman rank-order correlation coefficient of 0.694 over the 16 intersections studied between conflicts and accidents in the previous year. For those who would use an intermediate criterion, such as conflicts, rather than the elusive ultimate standard of accident reduction, this is encouraging indeed.

The driver comfort criterion that has been used in a number of instances (for example, *NCHRP Report 60* and work by Dunnette (*126*)) does appear to have a fair degree of sensitivity to small changes, but is difficult to relate to anything other than driver aesthetics and/or attentiveness. In short, this is often a useful adjunct to other measures, but does not appear to have the power to stand alone.

Vehicle dynamics such as spot speed, lateral placement, headways, acceleration, and deceleration profiles are so commonly used that no attempt is made here to cite specific instances. It can be logically concluded from their widespread employment as measures of effectiveness that they are both easy and practical to collect and possess sufficient sensitivity to reflect changes—even relatively minor ones. There is one outstanding drawback, however, and that is in interpretation. The difficulty arises in the fact that statistical significance and practical significance are not necessarily the same. For example, a shift of 6 in. in lateral placement away from the shoulder following application of edgelines may be statistically significant and, therefore, one can conclude that the treatment has had an effect. "Is the treatment effective?" is, in reality, a different question, because it implies improvement. Is a change of 6 in. in lateral placement an improvement? In most cases one cannot be sure that it is, although some convincing rational arguments can often be mustered. In the final analysis the mere fact that so many researchers have used measures of this type, plus the obvious inherent sensibility and practicality, argues strongly for their selection as a basis for the required development here. The problem lies in improving the rationale involved in interpreting the results obtained. Perhaps because the approach taken on this project is a more generally human-factors-oriented one, which focuses on the ability of the human to perceive, process, and take appropriate action based on information obtained from delineation systems, a possible solution to this problem is suggested. Perhaps the clearest statement of the point of departure for the logical derivation of the criteria to be employed here is found in Michaels' 1961 paper, where he writes:

> In the broadest sense, what is an accident? Essentially it is some kind of error. . . . It is no different in kind from the unavoidable small wanderings occurring in a car's traveling a tangent section of highway. As a matter of fact, any deviation from an ideal path represents an error in system operation and differs from an accident only in degree; the accident requires a collision of some sort. The real distinction between an accident and any other driving error is that it is usually terminal and destructive.

Expanding on this notión, he continues to define "error" as anything that causes the output of a system to deviate from what is predicted from knowledge of the input. Further, he distinguishes between constant and variable error. Then he makes two other highly pertinent observations:

> 1. For a given total variation (i.e., total error effect on the output) a certain proportion of the responses in the driving system will yield an error great enough to cause a collision.
>
> 2. . . . the objective of highway safety is to increase the reliability of the driving system (i.e., reduce error). Achievement of this objective must, coincidently, reduce the probability of . . . accidents. . . .

Now, although it is obvious that other sources of error exist, it is also apparent that the driver, who functions as the control element in the system, has a large potential for actively introducing error into the system; he, more than any other component, is likely to be the source of the "small unavoidable wanderings" mentioned by Michaels. Is it not logical, then, that in this analysis of delineation systems, which revolves around the perception, processing, and subsequent driver use of information, deviations from an ideal path are seen as a viable intermediate criterion? If the information conveyed is incomplete or inaccurate, if the perception is imprecise or inadequate, if the processing is incorrect or too slow, will not the action taken by the driver be likely to be in error to some degree? Further, it can be reasonably assumed that these "errors" will be manifest as "small wanderings" or "deviations from an ideal path."

At this point a persistent and important problem arises; namely, the definition, for any given situation, of "an ideal path." There is essentially no existing legal or physical one-and-only-one-right-way to negotiate any particular roadway geometry, nor can one be entirely satisfied with a consensus of experts because it is likely to be cast in general terms. It is precisely at this point that Michaels' concept of reliability enters the picture. If one could observe and quantify the *variation* observed in a sample of drivers performing a particular maneuver or negotiating a given section of roadway geometry, and, further, if the *amount* of variation was shown to be sensitive to changes in the associated delineation system, would not this constitute an index of effectiveness—an intermediate criterion? To clarify this point, consider the following example: A sharp horizontal curve with a design speed of 40 mph is currently delineated by means of an advance warning and speed advisory sign and a 4-in. painted edge line. Observation of 100 cars yields an average speed of 37 mph and an average lateral placement of the left wheels 2 ft from the center line at the point of curvature. Post delineators spaced in accordance with the federal manual and a 2 × 4-ft target arrow are added to the delineation system. Observation of 100 more vehicles yields the following: average speed = 35 mph, average lateral placement = 2.5 ft from center. Has the situation been improved? As noted before, it is unlikely that the absolute magnitude of these observed changes in the measures can be shown to be of practical significance. If, however, the observed *variability* in the second set of data was less than that in the first, it would be contended (following Michaels) that the situation had been improved. Less total variability implies that it is now less likely that deviations or errors large enough to result in a collision of any sort would occur. That is, because the range of observed responses (i.e., speeds and lateral placements) has decreased, the probability that responses more deviant than those observed will occur has also been decreased and therefore an accident at this location is now less likely.

SITUATION SELECTION PROCEDURES

The IDA approach suggested earlier in this section for use in establishing the driver's delineation needs is basically a successive translation from task requirements to information requirements. However, the task of deriving driver information requirements is, in and of itself, an activity that has little meaning and less operational value unless it is accomplished in a manner that enables the direct translation into delineation requirements and is ultimately tied to actual highway situations. It is because this fact was recognized (along with the reality that this project will have been of real value only it its outputs are used by traffic engineers) that the initial focus of this task was on the highway situation itself. In short, the process was begun where the traffic engineer must begin. Typical guidance, control, and warning situations currently handled via delineation were reviewed and cataloged. Because the bulk of the relevant source materials used in the initial compilation consisted of traffic engineering literature and state manuals, most of the situations selected for analysis were couched in geometric terms. Obviously, because of the rich variety of existing designs, the initial selection process did not result in an exhaustive listing of candidate situations; it did, however, provide a point of departure for the analysis of information requirements.

A preliminary review of the situations selected from the traffic engineering documents (see Table B-1) made it clear that the development of a performance model and the associated IDA analysis for each probably would result in a great deal of redundancy because of the apparent similarities among many of the situations. A simultaneous review of the general highway and human factors literature, the current practices survey data, and field observations, all argued for a more relevant definition of what constituted a highway "situation." It was decided, after considerable thought, that the most fruitful modeling approach would be to view the situation as a combination of geometry and a desired driver/vehicle maneuver. Furthermore, it was believed that the effectiveness of this effort would be enhanced if each model assumed optimal environmental conditions, because the literature is markedly devoid of definitive information as to the effects of these contingencies in typical traffic operations. Empirical documentation of these effects from other sources can, of course, be factored into the models.

Following these reviews, a second iteration of the situation classification began with a search for common elements in the original list and an analysis of the nature and extent of the demand that these various situations are likely to impose on the driver. Demand, for the purposes of this analysis, was considered from two standpoints: (a) the demand on the sensory systems (i.e., stimulus loading); and (b) demand in terms of behavioral output (i.e., response loading).

The initial task in the classification process was to reduce the nominal maneuvering aspects of the driving task to observable elements, of which there are two basic types—continuous and discontinuous. The continuous are those typically associated with maintenance of some desired (or required) quasi-steady state. The elements are: (a) adjustive lateral control (i.e., maintenance of desired or required position in the designated lane), and (b) adjustive longitudinal control (i.e., speed variations related to maintenance of appropriate headways, negotiation of curves, etc.)

The discontinuous elements are those typically associated with a change in state; e.g., leaving one roadway to change routes or streets. These elements are: (a) turn maneuvers, and (b) acceleration/deceleration.

Obviously, the discontinuous elements never occur entirely separately, because adjustive control is always required. Thus, a situation involving discontinuous elements always represents a higher stimulus and response load on the driver. Thought of in a slightly different way, the requirement for discontinuous elements is nearly always related to the transition from one quasi-steady state to another. The differentiation between the two types of elements becomes useful because the concept of transition requires special consideration of factors such as anticipatory information, stimulus competition, and higher information loads.

There are also cost and aesthetic implications to be considered in that a more or less continuous information input may be necessary for the adjustive control situations, a requirement that almost certainly affects the choice of an appropriate delineation treatment.

Another dimension in the structure considered factors related to the gross decision and task problems faced by the driver in each sitaution. This was analyzed in terms of: (a) the number of alternative choices available, and (b) whether the action is discretionary or dictated (i.e., by law, code, or geometry). The necessity for this breakdown results from the fact that situations involving a larger number of alternative decisions require more information lead time. Although it is true that some information regarding alternative choices is handled via directional signing rather than delineation, it was believed that at this stage of defining requirements these should be included. It was expected that the overlap (or integration) between directional signing and control behavior elicited by delineation would have important bearing on delineation system specifications.

The differentiation between discretionary and dictated actions was made because of the associated safety implications. That is, dictated actions (e.g., stop controls) are more likely to result in accidents if violated. The delineation treatments used for these situations, then, should be designed such that they are effective even in the face of low-probability traffic, highway, or environmental contingencies. This is not to say that these contingencies are to be minimized when considering treatments used for discretionary actions; there are, however, in most cases, differential "benefit" values associated with dictated vs discretionary actions and these were considered in the initial screening. Because of the wide variety of specific

TABLE B-1

DELINEATION SITUATIONS

1. Tangent section
2. Curve (vertical)
3. Curve (horizontal)
4. Funneled tangent
5. Flared tangent
6. Turn control (non-island/non-intersection)
   (a) Crossing
      (1) Right/left plus associated lane change
      (2) Oblique (weaving)
      (3) Opposed
   (b) Divergence (non-ramp)
      (1) Right/left
      (2) Mutual
      (3) Multiple
   (c) Merge (non-ramp)
      (1) Right/left
      (2) Mutual
      (3) Multiple
7. Turn control (islands and intersections)
   (a) Directional
      (1) Right turn
      (2) Left turn
   (b) Divisional
      (1) Teardrop (or ends of traffic separators)
      (2) Left turn, deceleration and storage lane
      (3) Left turn, acceleration lane
      (4) Left turn, accel./decel. plus storage lane
   (c) Median openings and crossovers
   (d) Refuge
8. Channelized intersections (non-signaled)
   (a) Narrow median, partial divisional
   (b) Narrow median, complete divisional
   (c) Narrow median, divisional/partial directional
   (d) Narrow median, complete divisional and directional
   (e) Wide median, complete divisional and directional
   (f) Complete divisional or directional (Y or skewed T)
9. Rotary intersections
10. Exit ramp complex
11. Entrance ramp complex
12. Stop control
13. Crosswalks
14. Railroad crossing approach
15. Obstructions
16. Pull-off
17. Passing zones
18. Grade separators
19. Parking lanes

TABLE B-2

"CLASSICAL" SITUATION FILE

CATEGORY	SITUATION
A. Quasi-steady state	1. Tangent 2. Curve, vertical 3. Curve, horizontal 4. No-passing zone 5. School zone
B. Minor transitional (lateral)	1. Flared tangent 2. Funneled tangent 3. Diverge 4. Merge 5. Weave 6. Multilane intersection through traffic
C. Minor transitional (longitudinal)	1. Railroad crossing 2. Crosswalk
D. Major transitional (longitudinal)	1. Stop approach
E. Major transitional (change in cardinal direction)	1. Left turn 2. Left turn with acceleration lane 3. Left turn with deceleration and storage lane 4. Right turn 5. Right turn with acceleration lane 6. Right turn with deceleration lane 7. U-turn

instances that can (and do) occur within any one situation type it became obvious after reviewing hundreds of candidate situations that exceptions to any rule were possible and that ambiguities of classification are highly probable occurrences in any logical (i.e., mutually exclusive, collectively exhaustive) structure.

CLASSICAL SITUATION FILE

The working classification used in lieu of a formal structure was essentially a rudimentary screening procedure that aided in the determination of which situations require unique models. This evolved from the review of a large number of situations and the development of IDA sequence cards for many that were potential candidates for delineation. This work revealed that a large majority of the situations that were initially assumed to be different were, in terms of IDA elements, really highly similar. For example, the IDA sequence for a driver negotiating a four-way intersection with complete divisional and directional channelization is virtually the same as that describing a four-way non-channelized intersection. Specifically, the actions are identical, the decisions the same (although more constrained with channelization); only the information provided is noticeably different, and this difference is mainly in amount rather than content or timing. Based on these findings, a decision was made to develop rational models for "classical" or typical situations. Those situations that were so identified are given in Table B-2.

One additional note regarding Table B-2—the internal grouping shown therein was logically derived from the discussion of continuous and discontinuous adjustive behavior and the distinction between quasi-steady state and transitional situations, and is based primarily on any disjunctive quality of the maneuver. Major transitions are considered to be those requiring a change in cardinal direction or a complete stop. The labels "longitudinal" and "lateral" relate to the major purposive nature of the action; i.e., the maneuver is performed because the driver desires or is required to change direction or velocity. For example, a merge, although highly dependent on longitudinal (relative

TABLE B-3

IDA SEQUENCES DEVELOPED FOR CLASSICAL SITUATIONS

SITUATION	ACTION SE-QUENCE	ACTION TO BE TAKEN	DECISION TO BE MADE	INFORMATION REQUIRED
A-1 Tangent, with passing	5	Maintain appropriate lane position.	Track/speed modification (if required).	Lane boundaries.
	4	Reestablish appropriate lane position.	Track/speed modification required for safe reentry to lane.	End of passing zone (or clearance of overtaken vehicle).
	3	Execute passing maneuver.	Track/speed modification required for safe passing maneuver.	Location/speed of other vehicles; lane boundaries.
	2	Initiate passing maneuver (if desired).	Pass maneuver, desirable and safe.	Location/speed of other vehicles; passing sight distance; land boundaries.
	1	Maintain appropriate lane position and headway.	Track/speed modification (if necessary).	Speed limit; location/speed of other vehicles; lane boundaries.
A-2 Curve, vertical (Speed tracking emphasized)	4	Reestablish desired crusing speed/track.	Termination of curve speed/track requirement.	Location of end of curve; lane boundaries.
	3	Maintain safe speed profile and lane position through curve.	Speed/track modification required.	Lane boundaries; degree of curvature.
	2	Establish appropriate speed for entry into curve.	Speed modification required.	Degree of curvature; speed advisory.
	1	Approach curve area.	Exercise caution; increase attention to speed tracking.	Advance warning of roadway change.
A-3 Curve, horizontal (Lateral track emphasized)	4	Reestablish desired cruising speed/track.	Termination of curve speed/track requirements.	Location of end of curve; lane boundaries.
	3	Maintain lane position and safe speed profile through curve.	Track/speed modification required.	Lane boundaries; degree of curvature.
	2	Establish appropriate speed and lane position for entry to curve.	Speed/track modification required.	Lane boundaries; degree of curvature; speed advisory.
	1	Approach curve area.	Exercise caution; increase attention to lateral track.	Advance warning of roadway change.
B-1 Flared tangent	5	Establish position in desired lane.	Tracking modifications required to position vehicle in lane.	Lane boundaries.
	4	Merge into new lane (if desired).	Speed and track modifications for safe merge.	Lane boundaries; location/speed of other vehicles; geometry of situation.
	3	Change lane (if desired).	Speed and track modifications required.	Lane boundaries; geometry of situation.
	2	Maintain lane position.	No change of current track and speed.	Lane boundaries.
	1	Enter flare area.	Exercise caution; increase surveillance sampling rate.	Advance warning of roadway change.
B-2 Funeled tangent (Lane drop, end climbing lane, etc.)	5	Establish position in new lane.	Tracking modifications required to position vehicle in lane.	Lane boundaries.
	4	Merge into new lane (if necessary).	Speed and track modifications required for safe merge.	Lane boundaries; location/speed of other vehicles; geometry of situation.
	3	Change lane (if necessary).	Speed and track modifications required.	Lane boundaries; geometry of situation.
	2	Maintain through-lane position.	No change of current track and speed.	Lane boundaries; geometry of situation.
	1	Enter funnel area.	Exercise caution; increase surveillance sampling rate.	Advance warning of roadway change.
B-3 Diverge, geometric	5	Establish position in desired traffic stream.	Tracking modification required.	Lane boundaries.
	4	Initiate divergence maneuver.	Appropriate location for tracking/speed modification to initiate maneuver.	Location of gore; lane boundaries.
	3	Establish position in appropriate lane for diverges.	Tracking/speed modification required.	Lane boundaries; location of gore; destination/direction.
	2	Maintain lane position.	No tracking modification required.	Lane boundaries; destination/direction.
	1	Enter diverge maneuver area.	Exercise caution; increase surveillance sampling rate.	Location of diverge area.
C-1 Railroad crossing	4	Clear danger zone and reestablish desired cruising speed.	Safe passage assured.	Location of railroad tracks; location of gates or barriers.
	3	Initiate crossing (accelerate).	Speed/track modification appropriate.	Location of crossing limits; location of gates, etc.; speed/location of railroad traffic.
	2	Approach crossing (decelerate).	Speed/track modification required.	Signals; sight/sound of railroad traffic; speed/location of other vehicles.
	1	Approach crossing approach.	Exercise caution; increase surveillance sampling rate.	Advance warning of railroad crossing.
C-2 Crosswalk	4	Clear area and reestablish desired cruising speed.	Safe passage assured.	Location of crosswalk limits.
	3	Initiate crossing (accelerate).	Speed/track modification appropriate.	Location of crossing limits; location of pedestrian traffic.
	2	Approach crossing (decelerate).	Speed/track modification required.	Speed/location of other vehicles; location of pecestrian traffic.
	1	Approach to crossing approach.	Exercise caution; increase surveillance sampling rate.	Advance warning of pedestrian crossing.
D-1 Stop approach	3	Complete stop.	Change in deceleration rate.	Limit of deceleration area (stop line).
	2	Initiate active deceleration (apply brake pedal).	Speed/track modification required.	Speed/location relative to limit of deceleration area available.
	1	Initiate deceleration (compression).	Speed/track modification (if necessary).	Advance warning of stop requirement.

E-1 Left turn	9	Establish lane position in appropriate lane.	Speed/track modification required.	Lane boundaries; location/speed of other vehicles.
	8	Complete turn maneuver.	Track/speed modification required.	Geometric limits of turn area; speed/location of other vehicles; lane entrance boundaries.
	7	Initiate turn maneuver.	Speed/track modification required for safe execution of turn.	"Turn corridor"; center of intersection; lane boundaries; opposing traffic.
	6	Traverse intersection to point of turn.	Speed/track modification required.	Turn angle; speed/location of other vehicles; special signals.
	5	Cross stop line (or point of entry to intersection).	Safe to proceed.	Intersection limit; speed/location of other vehicles; special signals.
	4	Approach intersection in appropriate lane and/or position in lane.	Speed/track modification necessary for correct position/headway.	Lane boundaries; location of intersection; speed/location of other vehicles.
	3	Enter appropriate lane and/or position in lane.	Path required for turn.	Destination/direction verification; lane boundaries.
	2	Initiate lane change (if necessary).	Lane change required to effect turn.	Destination/direction; lane boundaries; speed/location of other vehicles.
	1	Approach vicinity of intersection.	Exercise caution; desired route requires left turn.	Destination/direction; advance warning of intersection; intersection geometry.
E-2 Left turn, with accleration lane	12	Establish lane position in appropriate lane.	Speed/track modification required.	Lane boundaries; location/speed of other vehicles.
	11	Merge from acceleration lane (if necessary).	Speed/track modification required for safe merge.	Lane boundaries; acceleration lane limit; speed/location of other vehicles.
	10	Maintain appropriate position/headway in acceleration lane.	Speed/track modification required.	Lane boundaries; acceleration lane limit; speed/location of vehicles.
	9	Enter acceleration lane.	Path required for turn (speed modification if required).	Lane entrance boundaries; acceleration lane limits; speed/location of other vehicles.
	8	Complete turn maneuver.	Speed/track modification required.	Geometric limits of turn area; speed/location of other vehicles; lane entrance boundaries.
	7	Initiate turn maneuver.	Speed/track modification required for safe execution of turn.	"Turn corridor"; center of intersection; lane boundaries; opposing traffic.
	6	Traverse intersection to point of turn.	Speed/track modification required.	Turn angle; speed/location of other vehicles; special signals.
	5	Cross stop line (or point of entry to intersection).	Safe to proceed.	Intersection limit; speed/location of other vehicles; special signals.
	4	Approach intersection in appropriate lane and/or position in lane.	Speed/track modifications necessary for correct position/headway.	Lane boundaries; location of intersection; speed/location of other vehicles.
	3	Enter appropriate lane and/or position in lane.	Path required for turn.	Destination/direction verification; lane boundaries.
	2	Initiate lane change (if necessary).	Lane change required to effect turn.	Destination/direction; lane boundaries; speed/location of other vehicles.
	1	Approach vicinity of intersection.	Exercise caution; desired route requires left turn.	Destination/direction; advance warning of intersection; intersection geometry.
E-3 Left turn, with deceleration and/or storage lane	10	Establish lane position in appropriate lane.	Speed/track modification required.	Lane boundaries; location/speed of other vehicles.
	9	Complete turn maneuver.	Track/speed modification required.	Geometric limits of turn area; speed/location of other vehicles; entrance lane.
	8	Initiate turn maneuver.	Speed/track modification required for safe execution of turn.	"Turn corridor"; center of intersection; lane boundaries; opposing traffic.
	7	Traverse intersection to point of turn.	Speed/track modification required.	Turn angle; speed/location of other vehicles; special signals.
	6	Cross stop line or point of entry to intersection.	Safe to proceed.	Intersection limit; speed/location of other vehicles; special signals.
	5	Maintain appropriate headway/position in storage lane.	Speed/track modifications necessary for correct position/headway.	Lane boundaries; location of intersection; speed/location of other vehicles.
	4	Enter deceleration/storage lane.	Path required prior to turn.	Destination/direction verification; lane boundaries; situation geometry.
	3	Establish position in appropriate lane (for decel/storage lane entry).	Lane appropriate for decel/storage lane entry.	Situation geometry; lane boundaries; speed/location of other vehicles; directional.
	2	Initiate lane change (if necessary).	Lane change required to effect decel/storage lane entry.	Destination/direction; lane boundaries, speed/location of other vehicles; situation.
	1	Approach vicinity of intersection.	Exercise caution; destination-related requirement for left turn.	Destination/direction; advance warning of intersection; intersection geometry.
E-4 Right turn	8	Establish lane position in appropriate lane.	Speed/track modification required.	Lane boundaries; speed/location of other vehicles.
	7	Complete turn maneuver.	Speed/track modification required.	Geometric limits of turn area; entrance lane boundaries; speed/location of other vehicles.
	6	Initiate turn maneuver.	Speed/track modification required for safe execution of turn.	"Turn corridor"; curb line; lane boundaries.
	5	Cross stop line (or point of entry to intersection).	Safe to proceed.	Intersection limit; signals; speed/location of other vehicles.
	4	Approach intersection in appropriate lane and/or position in lane.	Speed/track modification necessary for correct position/headway.	Lane boundaries; location of intersection; speed/location of other vehicles.
	3	Enter appropriate lane and appropriate position in lane.	Path required for turn.	Destination/direction verification; lane boundaries.
	2	Initiate lane change (if necessary).	Lane change required to effect turn.	Destination/direction; lane boundaries; speed/location of other vehicles.
	1	Approach vicinity of intersection.	Exercise caution; desired route requires right turn.	Destination/direction; advance warning of intersection; intersection geometry.

velocity) adjustments, is listed under "lateral" because the end result of the action is a lateral change.

Employment of these "classical" situation models and the inherent rudimentary structure had the advantage of permitting comparisons of specific situations without the necessity for extensive formal preparation of IDA sequence cards for each slight situational variation. Thus, a large number of situations were covered in a cost/effective fashion. The sole requirement was that each new situation encountered be coded as to the "best fit" classical model. In cases where the IDA elements and their sequences matched, but temporal requirements differed substantially, a notation system was employed to specify the magnitude and direction of such differences directly on the relevant IDA model. The frequency of occurrence of a deviation pattern determined whether or not a separate model was necessary.

The most time-consuming task related to model development was the compilation of the quantitative data necessary to generate and/or support the qualitative aspects of the IDA sequences—How long does it take to perform various actions or maneuvers? What is known about the distribution of gap availability for lane changes? Because in most cases the literature relevant to the models was also appropriate for inclusion in the state-of-the-art review, duplication of effort was avoided by fully annotating articles.

IDA SEQUENCE FILE

The decision to base the IDA sequencing on a limited number of classical situations rather than attempting separate analyses of minor variations necessitated employment of certain limiting assumptions. These fundamental notions served as guidelines regarding specificity/generality balance among situations and reduced the amount of redundant notation that would have resulted from including behaviors that occur repeatedly within each situation. In reviewing the IDA sequences, the following major points should be kept in mind:

1. Only behaviors that have immediately observable external consequences were included as action elements. That is to say, the focus was on "behavior" of the vehicle/driver in terms directly amenable to measurements under actual traffic conditions in the field. This deliberately excludes the more microscopic behaviors involved in continuous adjustive tracking that would be directly observable only from a vantage point within the vehicle or via vehicle-mounted measurement equipment.

2. In any traffic situation the driver is constantly required to process information about the speed and location of other vehicles in the environment. Only a portion of this activity, however, interacts directly with delineation information. Therefore, the IDA sequences were limited to attending to this class of information only when it does affect an action that is delineation-related. For example, when a lane-change maneuver is required to position the vehicle for entry into a deceleration-storage lane, the effect of stream speeds and volume on average gap size and availability and consequent delay in changing lanes is factored into the model. Conversely, the presence (or average probability) of crossing traffic or opposing traffic within an intersection is not a factor because it does not relate to actions that are delineation-controlled or modified.

3. Where legal sanctions are involved (e.g., stop approaches) it was assumed that the driver desires to obey the law. Therefore, decision alternatives (e.g., to stop or not) are not included in the sequence.

4. In all situations involving a directional change (e.g., left turns, exit ramps) the model attends only to the driver who wishes to make such a change. In these cases directional/destinational signing provides the driver with the relevant information and it is assumed that such information has been transmitted and processed at an earlier time (i.e., prior to arrival at the transitional geometry). Only the problem of correlating the destinational/directional information with the geometry will be attended to, where necessary, in the IDA sequences.

5. In intersectional situations, the model deals with only one leg of the intersection (or one direction of travel) at a time. Although it is realized that in a multi-leg intersection having several different types of channelization there may be some informational interaction, the problems involved in traversing the situation can be solved (for an individual driver) for only one direction at a time. Therefore, each type of channelization (e.g., left turn deceleration and storage) is handled separately. When using several different such configurations in a single intersection, the engineer can use the requirements developed as general guidelines and use engineering judgment to make modifications necessary to effect the required combination.

IDA Sequences

The IDA sequences that were developed for each of the classical situations are given in Table B-3. The format of these sequences is such that, in effect, they are ADI sequences; i.e., the *action* to be taken was the reference or starting point, then the *decision* associated was inferred, and finally the *information* required was identified. One other "reversal" was built into the format—again in order to facilitate the specification of elements for this phase of the work; the ADI's were listed with the terminal action first, working backwards to the driver's point of entry into the situation.

MODEL DEVELOPMENT

The IDA sequence elements were derived on the basis of a rational analysis of driver maneuvers over a number of situations in a particular class. Thus, it was not surprising that a final review indicated a need to further cull out excessive redundancy in preparation for full model development. The principal selection guideline employed here was to eliminate situations that could be considered to be combinations of elemental maneuvers contained in other situations (e.g., the weave situation is a combined diverge and merge). A second selection factor argued for pruning those maneuvers that involved only continuous tracking and little or no transitional action (typical of these were the tangent and vertical curve situations). Finally, because the completed models were to serve as basic data for the experimental phase of this project, a decision was made to put greater emphasis on situations that had not been the subject of recent and intensive research and/or those that promised the greatest potential benefit through delineation. Based on the latter point, freeway ramps were omitted because of the attention given them by the Federal Highway Administration; similarly, railroad crossings were eliminated due to a sizable NCHRP effort (*NCHRP Report 50*).

Those situations selected for complete model development are fully expanded in Appendix A. Briefly, the complete model of a "classical" situation consists of (1) the IDA sequence, (2) the geometric diagram, (3) supportive data relating the elements of the IDA sequence to the situation diagram, (4) a set of measureable dependent variables, and (5) possible techniques for obtaining the selected measures.

If it could be reasonably assumed that the existence of other vehicles in the immediate area did not affect the driver's action and did not interact with the delineation system, the complete detailing of the five components of the models would be a routine affair. That is to say, in the absence of other vehicles, effective delineation systems could be designed on a strictly physical and/or psychophysical basis, depending only on the driver's perceptions, reaction time, etc. This is obviously not an accurate or useful view of the situation reality, because perhaps the most constraining variables in the modeling effort are those related to traffic stream characteristics. The key to developing meaningful models is in the comprehensive incorporation of the effects of known traffic stream characteristics, both fixed and variable, into the models. Lane volumes, stream speeds, comfortable deceleration rates, average delays, average gap size, gap availability, and numerous other factors will affect both the timing and the location of required actions within a situation and, therefore, the requisite information lead distance. To be truly useful the models of the classical situations must explicitly deal with these contingencies and distribute their effects to the appropriate points in the over-all sequence.

To the extent possible, a dualistic human factors and traffic engineering approach was applied to each of the models. It should be noted, however, that directly relevant and updated empirical data on traffic operations were extremely scarce. Hence, source material for supportive data, although derived from standard reliable references, is, in some respect, questionable because of changing road and vehicle characteristics. For example, improved braking and suspension systems may have significantly altered what is now perceived as a comfortable rate of deceleration. The consequence is that delineation treatments could be less than optimally effective using current data, inasmuch as information would, in general, be provided too early. This argues for establishing traffic parameters on the basis of what the driver now does instead of what traffic design engineers believe he should do. It is in this area that the existing literature is severely deficient.

APPENDIX C

DELINEATION TREATMENTS *

The material in this appendix deals primarily with the physical aspects of the delineation treatments in common use. The effects of the various treatments on traffic operations are discussed in Appendix A. The subsections of this appendix are pavement markings, post delineators, raised pavement markers, colored pavements, rumble strips, curbs, indirect methods, and systems of treatments. Under each of these headings are provided comments and findings relevant to materials, maintenance, costs, and environmental effects, as well as a synthesis and evaluation.

The material within the subsections has been collected and integrated by project personnel. However, reference notes follow certain paragraphs that report specific comments, findings, or reported results from the literature, current practices interviews, or discussions with nonproject personnel. The code for these reference notes is the same as that described in Appendix A under "Current Practices and Related Research."

In general, each section has a short introduction, followed by an organized presentation of specific research results and/or relevant comments. These comments are capsuled so that the reader can easily determine the source for his own interpretation and evaluation. It is not intended that these discussions be exhaustive; rather, that new and/or unique findings would be reported on the assumption that readers of this section will be familiar with standard treatments and applications. At the end of each section, a synthesis and evaluation is provided.

PAVEMENT MARKINGS

Taken in the broadest sense, a pavement marking can be any material placed directly on the pavement that acts as or simulates a longitudinal or transverse line or symbol.

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As such, "pavement markings" include the following types of materials: (1) paint, (2) thermoplastic compounds, (3) wedges, (4) buttons, and (5) built-in permanent markings (color or texture contrast). However, this section discusses only standard paint and thermoplastic compounds; subsequent sections take up features of other materials.*

Materials

Pavement marking materials can be classified in two broad categories, as follows:

1. Paint (reflectorized and non-reflectorized).
2. Plastic compounds (reflectorized and non-reflectorized).
   (a) Hot-extruded.
   (b) Hot-laid.
   (c) Cold-laid.
   (d) Preformed tape.

1. Paints, the most common material for placing pavement markings, come in a variety of bases, including alkyd, rubber, vinyl, epoxy, water base, and high-polymer. Apparently, no one type of paint is best suited for every color and for every situation. However, New York reported that a modified alkyd with 40 percent titanium dioxide was the best performing white paint with least cost. The best performing yellow paints were the modified alkyds and modified alkyds-chlorinated rubbers. (New York, 1969, *77*)

2. Georgia recommends a film thickness of ⅛ in. for hot thermoplastic strips. The surface should be clean and dry, and priming with clear epoxy resin is essential for adequate performance of thermoplastic on portland cement concrete pavements. (Georgia, 1968, *94*)

3. Cold-applied plastic tape has a core of soft aluminum coated on the top side with a white or yellow vinyl layer and reflectorized with glass beads. The bottom side is layered with a pressure-sensitive asphaltic compound that is used with a primer to bond the tape to the roadway. The tape is very effective for temporary pavement markings in areas where retained paint lines would be objectionable.

Many states have investigated different types of thermoplastics as compared to standard pavement markings. Some of their conclusions are:

1. The most economical hot thermoplastic composition is not fully competitive with traffic paint. The service life of hot thermoplastic should be at least 6.3 times that of traffic paint for full economic parity. Thermoplastics are not recommended for general highway use, but are used in some special situations, such as at crosswalks. (Georgia, 1968, *94*)

2. Hot-applied thermoplastic appears to be more economical than standard paint for intersection markings where two-way ADT exceeds about 2,500. Cold-applied thermoplastics and hot-applied, pellet-type thermoplastic are warranted only under special conditions. (Florida, 1968, *93*)

3. Based on its performance in Minnesota, the effective life of thermoplastic is only 1½ years on PCC pavements. It was concluded that thermoplastic should not be used as a pavement marking material on concrete pavement in Minnesota. The service life of thermoplastic on bituminous pavements is related to the traffic volume on straight sections of roadway, while the service life on curve sections appears to be about two years. In general, thermoplastic can be used economically on bituminous pavements having ADT's per lane ranging from 2,000 to 7,000. (Minnesota, 1970, *80*)

4. Cold-applied plastic tape is not as durable on crosswalks and lane lines as the thermoplastic traffic stripe. A lack of adhesion and distortion of the plastic tape under traffic in crosswalks is reported, caused by turning action and rapid acceleration of vehicles. The material cost of the plastic tape is about twice that of thermoplastic stripe and the labor costs are about equal . (California, 1967, *54*)

5. Daytime and nighttime visibility of thermoplastic stripe are superior to that of standard paint stripe. Thermoplastics perform better on bituminous surfaces than on portland cement concrete because they fuse to the asphaltic surface, ensuring a good bond. Thermoplastic lines cost $0.395 per foot, whereas standard paint costs only $0.016 per foot. (Kentucky, 1964, *75*)

6. With the exception of the 4-in. shoulder lines, all standard paint lines had worn to the degree that they were no longer functional after a period of two months during the winter. Although many thermoplastic lines were shattered at the ends by snowplowing operations, these lines were still effective. Severe blistering of thermoplastic lines was experienced on portland cement concrete pavements. (Connecticut, 1963, C)

7. California conducted tests to determine the skid characteristics of thermoplastic vs painted stripes. Although they showed that skid resistances on thermoplastic stripes are low, they concluded that there does not appear to be any greater hazard in vehicle operations over thermoplastic stripes than that encountered over presently used paint stripes. In both instances some loss of control occurred when braking with two wheels directly on 8-in.-wide stripes. (California, 1965, *82*)

Chaiken conducted a nationwide survey on the use of hot-extruded thermoplastics and conventional paint for highway striping. He evaluated the comparative durability, performance, and economy of these traffic marking materials and showed that the relative durability and long-term economy of thermoplastic striping materials were greatly affected by type of pavement, snowplow activity, and traffic density. A guide chart (Fig. C-1) was developed to facilitate selection of the more economical of the two marking materials. (Chaiken, 1969, *44*)

Maintenance

1. New York reported three particular forms of paint deterioration, as follows:
   (a) Abrasion or erosion caused by wear from tires, snowplows, sanding operations, weathering, or combinations of these factors.
   (b) Scaling or chipping, occurring mostly on port-

* Two reports (*44, 45*) by B. Chaiken should be noted as substantial contributions to the state of the art of pavement marking materials. Highlights of these papers are incorporated into this section.

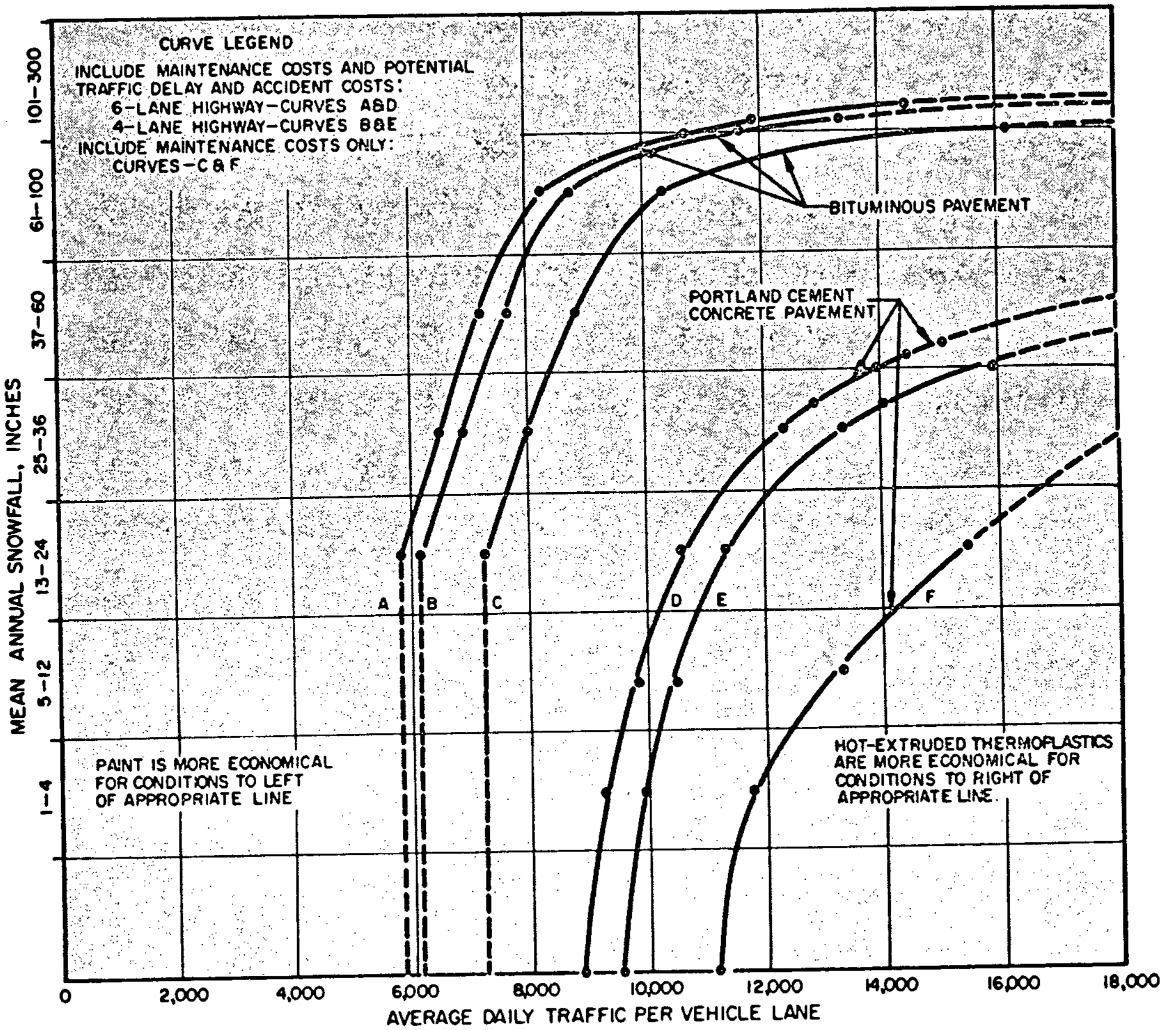

Figure C-1. Guide for selecting the most economical striping material; paint vs thermoplastic.

Source: Chaiken, B., "Comparison of the Performance and Economy of Hot-Extruded Thermoplastic Highway Striping Materials and Conventional Paint Striping." *Pub. Roads*, Vol. 35, No. 6, Feb. 1969, p. 149.

land cement concrete where there is little adhesion between the paint film and the underlying surface.

(c) Discoloration due to dirt from tires or chemical reactions. (New York, 1969, *77*)

2. Colorado claims that chipping of traffic paint is the predominant cause of failure. (Colorado, 1968, *63*)

3. Kansas also reports paint chipping as the major problem in paint loss, with wear or abrasion as a minor problem. The service life of paint stripes is often more dependent on the surface conditions of the road than on the thickness of the paint film. (Kansas, 1969, *84*)

4. Concrete pavements, being porous, allow water to rise up through them; this action, plus the highly alkaline environment, contributes to the often observed more rapid failure of paints on concrete through loss of adhesion. (SRI, 1967, *48*)

5. State highway officials have indicated that painted lines rarely last more than a year, and in states subjected to a winter environment paint lines quickly fade during the winter season. New Hampshire reported that they tend to use less expensive paints on open highways because even the better paints do not last through the winter. (New Hampshire, 1969, B)

6. Snowplowing causes shattering of the ends of thermoplastic lines. (Connecticut, 1965, C)

Costs

Four state highway departments indicate the following costs for standard painted lines:

1. Iowa—807 miles of beaded white edge line cost $74.90 per mile and 10,551 miles of center line and barrier line cost $52 per mile. (Iowa, 1965, *94*)

2. In 1963, New York spent an average of $0.017 per foot ($89.76 per mile) for 4-in.-wide reflectorized stripe. Of this cost, 36% was attributed to the paint itself and 64% to beads, labor, equipment, and operations. (New York, 1963, *77*)

3. In 1968, it cost New Hampshire $43.18 for a mile of 4-in. beaded line on non-Interstate road. On the Inter-

state system, the painted line cost $49.57 per mile. (New Hampshire, 1969, B)

4. Kansas reported the cost breakdown of their paint striping operations to be: materials (paint, beads, and naphtha), 74%; labor, 19%; equipment operation and depreciation, 7%. (Kansas, 1969, *69*)

The average installation cost of paint striping for open highways on a national basis was determined to be $0.022 per linear foot ($116/mile) of 4-in. longitudinal striping (Chaiken, 1969, *44*). Table C-1 gives the annual cost of conventional paint striping for a 1-ft length of a 4-in.-wide paint stripe, considering its useful service, cost of traffic delay, and cost of potential traffic accidents.

Thermoplastic paint lines are considerably more expensive, as reflected by these cost figures from two states:

1. Iowa—In 1964, a 4½-in. white line on a freeway cost $0.465 per foot; $0.645 per foot for an 8-in. line. (Iowa, 1965, *83*)
2. Kentucky reported a cost of $0.395 per foot in their study of thermoplastics. (Kentucky, 1964, *75*)

A nationwide survey by the Bureau of Public Roads shows the average cost for 4-in. longitudinal thermoplastic striping to be $0.327 per foot. (Chaiken, 1969, *44*)

Michigan reported a cost of $0.14 per foot for temporary cold-applied plastic tape. This compares favorably with paint striping in construction areas, where the cost of removal alone is $0.10 per foot. (Michigan, 1965, *85*)

Environmental Effects

Dale, in his efforts to develop an improved pavement marking material, makes the following observations regarding the environmental effects on the visibility of pavement marking materials:

1. It has been noted that during daylight hours precipitation often improved delineation of the roadway by improving the contrast between the road surface (generally darker when wet) and the markings.
2. The problem of water film on the center line of a crowned two-lane, rural highway is essentially one of the water falling on the marking material and flowing off in both directions, so that there is little tendency for buildup from adjacent runoff. However, water falling in the center builds up a runoff pattern that crosses the edge line transversely, thus producing a thicker water film.
3. Conditions of moisture in the wet nighttime environment produce effects that are almost entirely detrimental. In addition to wetting and submerging the marking materials and their reflective elements, the light from approaching automobiles is reflected off the water on the pavement surface and forward to the approaching vehicle, greatly magnifying the headlight glare problem and making surface-marking materials more difficult to perceive.
4. Depending on the road contour and during ideal dry-weather conditions, pavement marking materials with glass beads properly applied can be easily distinguished at night with high-beam headlights well beyond 350 ft, where there is no opposing traffic. (SRI, 1967, *48*)

Although pavement markings would generally be considered "ineffective" in fog, they probably are the best means of delineation available to the driver in this condition (reflective raised pavement markers may be visible at greater distance where they are available, as discussed subsequently under "Raised Pavement Markers").

During snow conditions, pavement markings become totally ineffective because they are then completely covered. Also, snow removal operations using deicing salts have a deleterious effect on the life of pavement markings.

Other Comments

Several states and research agencies have investigated the use of traffic beads for pavement markings. Some of the findings are:

1. Colorado:
   (a) Glass spheres having a refractive index in the range of 1.5 to 1.6 can be a satisfactory material for reflectorizing painted strips on a roadway surface.
   (b) Treatment of the glass spheres to make them float on a film of paint is an effective means of increasing their nighttime reflectance.
   (c) Evaluation showed that a new product—small uniformly graded beads that float on a xylol solution—when placed at the rate of 4 lb of beads per gallon of paint, was brighter and more durable over a 10-month testing period than the old product placed at the rate of 6 lb of beads per gallon of paint. (Colorado, 1968, *75*, *64*)
2. New York:
   (a) Beads with a high index of refraction (1.65+) initially provided greater reflectance on portland cement concrete pavements than beads with an index of refraction between 1.50 and 1.65. However, after about eight weeks the reflectance diminished to a level similar to that of the lower index beads due to poor retention by the traffic paint.
   (b) On an asphaltic concrete surface the high index of refraction beads consistently reflected more light than the standard beads. However, the difference was barely visible even though it could be measured with a photometer. (New York, 1967, *76*)
3. Southwest Research Institute:
   (a) Great benefits are seen from the use of beads that are essentially of the same diameter, the diameter selected being the one that will result in the beads being imbedded in the binder to 55 to 65 percent of their vertical height.
   (b) The use of glass beads with a high refractive index and the use of larger quantities of glass per unit of stripe offer improvements in the field; however, it would appear that greater dividends would accrue from the better utilization of glass beads having a low refractive index (and costing less) through improved bead-gradation specifications and application techniques. (SRI, 1967, *48*)

TABLE C-1

ANNUAL COST OF CONVENTIONAL PAINT STRIPING (Costs given separately and collectively for basic installation, traffic delay, and potential accidents)

	Average daily traffic (ADT) per lane—No. of vehicles															
	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000
Useful paint life [2] ....years..	1.32	1.02	0.87	0.75	0.67	0.60	0.55	0.50	0.45	0.42	0.38	0.36	0.35	0.33	0.32	0.31
Annual striping frequency [3]	.76	.98	1.15	1.33	1.47	1.67	1.82	2.00	2.22	2.38	2.63	2.78	2.86	3.03	3.12	3.22
Annual basic paint striping cost, per linear ft. per year (A) [4] ....cents..	1.67	2.16	2.53	2.93	3.28	3.67	4.00	4.40	4.88	5.24	5.79	6.12	6.29	6.67	6.86	7.08
Annual costs of paint striping on 4-lane divided highway:																
Cost of traffic delay, per linear ft. per year (B) [5] ....cents..	.02	.05	.11	.16	.23	.31	.39	.49	.61	.73	.89	1.02	1.14	1.30	1.43	1.58
Cost of potential traffic accidents, per linear ft. per year (C) [6] ....cents..	.00	.01	.01	.02	.03	.04	.05	.06	.08	.10	.12	.13	.15	.17	.19	.21
Total annual cost, per linear ft. per year (A)+(B)+(C)....cents..	1.69	2.22	2.65	3.11	3.54	4.02	4.44	4.95	5.57	6.07	6.80	7.27	7.58	8.14	8.48	8.87
Annual costs of paint striping on 6-lane divided highway:																
Cost of traffic delay, per linear ft. per year (D) [5] ....cents..	.03	.07	.16	.25	.34	.46	.59	.74	.92	1.10	1.33	1.54	1.71	1.96	2.16	2.39
Cost of potential accidents, per linear ft. per year (E) [6] ....cents..	.00	.01	.02	.03	.04	.06	.08	.10	.12	.14	.17	.20	.22	.25	.28	.31
Total annual cost, per linear ft. per year (A)+(D)+(E)....cents..	1.70	2.24	2.71	3.21	3.66	4.19	4.67	5.24	5.92	6.48	7.29	7.86	8.22	8.88	9.30	9.76

[1] Applicable to longitudinal striping of 4-inch wide center and lane lines, excluding edge lines, on open highways as typified by Interstate roads.
[2] Interpolated from figure 4.
[3] Calculated from data on *useful paint life.*
[4] Basic materials, labor, and installation costs calculated from: annual striping frequency × 2.2¢ (average cost per linear foot of 4-inch stripe per installation, as explained in text).
[5] Calculated from: 7.65 × 10^{-6} × total ADT × annual striping frequency (equation 1 in text).
[6] Calculated from: Total ADT × 10^{-6} × annual striping frequency (equation 2 in text).

Source: Chaiken, B., "Comparison of the Performance and Economy of Hot-Extruded Thermoplastic Highway Striping Materials and Conventional Paint Striping." *Pub. Roads,* Vol. 35, No. 6, Feb. 1969, p. 149.

4. Christensen Diamond Service has developed a diamond texturing and grooving configuration that, when painted with paint and reflective beads, provides reasonable visibility under the most adverse conditions (Fig. C-2). A transverse drainage groove allows any rainwater to drain away from the stripe area, resulting in increased wet night visibility. In addition, the grooved stripe produces a rumble effect. Costs reportedly range from $0.22 to $0.32 for installation of 10,000 lineal feet or more, depending on the degree of state participation. The life of the paint, with only 5-mil coating, is reported to be three times that of normal painted lines. Although applications have been made in some states, only preliminary reports attesting to the effectivenes of the grooved line are available. (Utah, 1969, *71*)

5. Tucker Associates, of Palo Alto, Calif., have introduced pyramidal traffic markings for one-way roadways (Fig. C-3). The normal rectangular lane line is replaced by a pyramid line with the apex pointing toward the intended direction of flow. All materials used to make lane lines can be used to make the pyramidals. It is proposed that the markings be dashed to allow lane changing, or continuous to prohibit lane changing. Wrong-way drivers would see the apex aimed towards them and, hopefully, would be alerted to the fact that they are driving the wrong way. To date, no reports have been published evaluating this pavement marking. (Tucker, 1969, D)

Synthesis and Evaluation

By far the most commonly used pavement marking material is standard paint, with or without glass beads. On the open highway, it is used almost exclusively; thermoplastics and plastic tapes find some application in urban areas and other special situations.

On a cost basis, thermoplastic markings are roughly 15 times more expensive to install than standard paint lines. The average cost of hot-extruded thermoplastic lines is $0.327 per foot, whereas the average cost for reflectorized paint line is $0.022 per foot. Cold-applied tape costs are somewhat lower than the hot-extruded thermoplastic materials.

There are, however, other advantages to using thermoplastics that can offset their higher cost. Because restriping is not required as frequently, the maintenance crew is not subjected to traffic hazards as often. Similarly, accident potential is reduced, as well as traffic delay to the public. In urban areas these savings can be substantial enough to warrant the use of thermoplastics.

Regardless of the material used, pavement markings are adversely affected by bad weather. In snow they are completely obliterated, and in wet weather their effectiveness is greatly reduced. Any substantial amount of water on the pavement will cover the beads and seriously impair their reflectivity. Because of this adverse environmental effect, traffic engineers have utilized post delineators and other raised markers for supplemental delineation. Many states have expressed the desire for all-weather, all-purpose delineators that could be placed on the pavement.

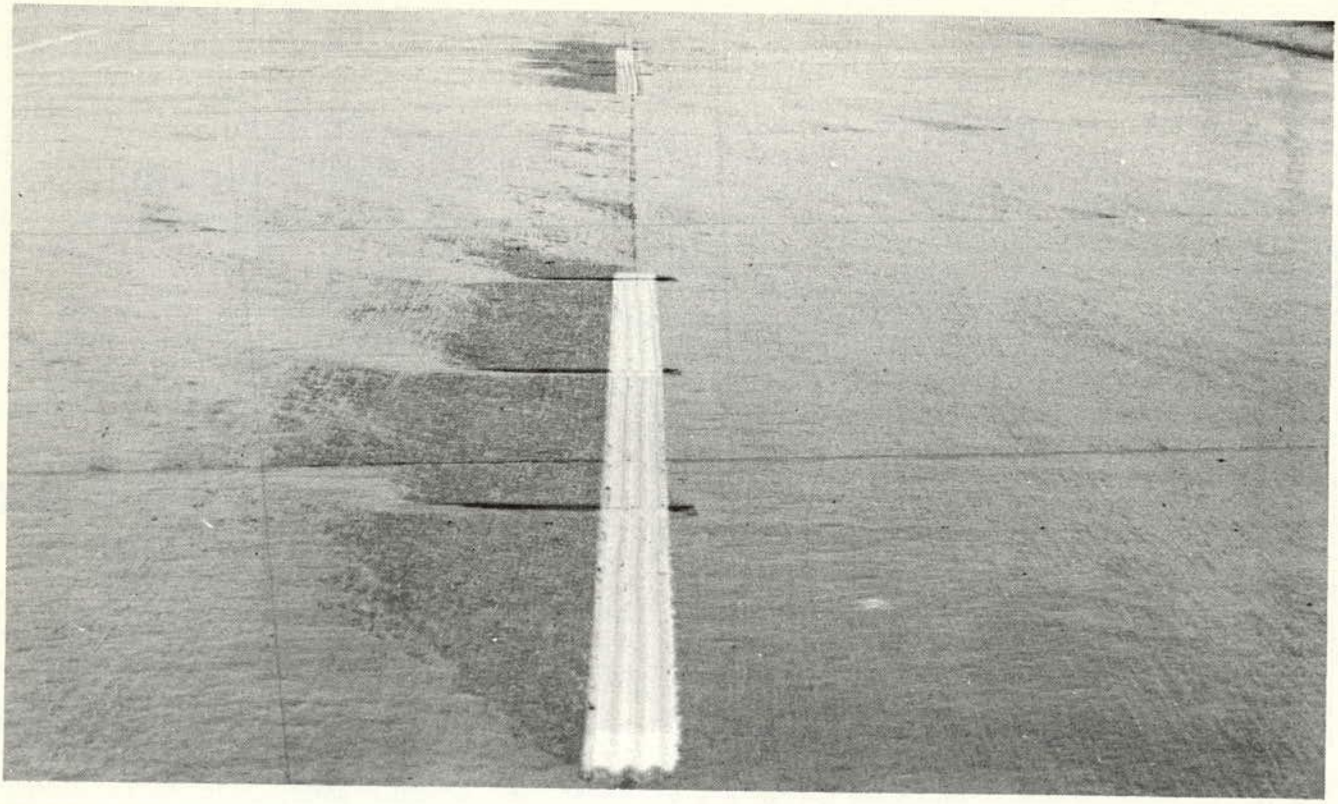

Figure C-2. Diamond-grooved paint stripe, Utah.

POST DELINEATORS

It is commonly understood that post delineators are retroreflective markers placed on wood or steel posts and located just outside the right or left shoulder edge. The delineators receive their reflectivity by returning an incoming light ray in an opposite and nearly parallel direction. The delineators are normally placed from 3 to 4 ft above the pavement, making them visible during inclement weather when pavement markings become ineffective.

Materials

Post delineators, commonly referred to as retro-reflectors, are of two types—image forming and trihedral. The first type employs small glass beads bound to a rigid backing plate. The second type consists of a triple mirror arrangement repeated numerous times within the reflector housing. (E)

1. The U.S. Coast Guard Testing and Development Division conducted field testing of the intensity properties of four different types of retroreflective delineators found on the market. Their results indicate that the specific intensity of the trihedral-type delineator is superior to the image forming delineator at low incidence angles. However, the trihedral delineator changes its optical characteristics as its orientation angle is varied, whereas the image delineator maintains its specific intensity through a wider range of incidence angles. (U.S. Coast Guard, 1963, *56*)

Although various colors are used for delineators in many states, only two colors—white and yellow—are sanctioned by the Federal Highway Administration (FHWA) on the Interstate System. As specified by the *Manual on Uniform Traffic Control Devices* (1961), white delineators are reserved for marking through roadways, whereas yellow delineators are used for ramps at interchanges and as hazard markers.

2. In some interchange studies, such as in Minnesota, Michigan, and North Carolina, blue delineators were used on exit ramps. (Minnesota, 1960, *26;* Michigan, 1965, *91;* North Carolina, 1969, B)

3. Green has been used to designate hazards (Michigan, 1969, *62*) and a combination of blue and yellow has been used to mark median crossovers. (Florida, 1969, B)

4. Specific intensities of the colored retro-reflectors are lower than those of the clear reflectors. Fitzpatrick shows evidence that yellow reflectors have a higher luminance level than blue reflectors. (Fitzpatrick, 1960, *72*)

5. California attaches their retro-reflectors to a rectangular white paddle mounted on a timber or steel post. There has been consideration on their part as to the desirability of the white paddle, however. (California, 1969, B)

6. Arizona indicated the use of a steel panel marker with diagonal black and white stripes in their report on post delineator effectiveness. (Arizona, 1963, *41*)

7. North Carolina uses black with white, yellow, or fluorescent orange diagonal-striped panels of various sizes from $3\frac{1}{2} \times 12$ in. to 12×36 in. as post delineators. (North Carolina, 1969, B)

Maintenance

The actual delineator, regardless of the type, has a long life provided it is kept clean and is not damaged by shoulder-encroaching vehicles. However, vehicles and snow removal equipment frequently damage both the post and the delineator when they encroach on the shoulder. (E)

1. New Hampshire reported that during the 1968-69 winter season, 75 percent of their post delineators needed repair or replacement; for the average winter this figure is about 50 percent. (New Hampshire, 1969, B)

2. Several states have begun to use flexible posts, especially on the median islands. These posts can be run over repeatedly without damage. (E)

3. In an effort to reduce the high rate of damage to their metal posts supporting delineators, the Alabama Highway Department painted some posts orange to contrast with the background. Their study indicated that a saving could be realized by painting the posts. (Alabama, 1968, *49*)

4. A significant maintenance problem is keeping the delineator clean of road film splashed on by vehicles. Even with the delineators placed 4 ft above the ground, the retro-reflectors become dirty and decreased reflective intensity results. (E)

Cost

1. Alabama reported that delineator posts with a single 3-in. reflector button cost $3 when installed under an original construction contract. At this price and with a spacing of 200 ft on tangent sections, a mile of post delineators would cost $78. The post itself constitutes a major portion of the cost, with the reflector button priced at about $0.50. (Alabama, 1968, *49*)

2. In Peoria County, Ill., 3×8-in. reflectorized sheets mounted on metal posts have a contract cost of $5.50 each when ordered in quantities of 1,000 to 2,000 posts. (Illinois, 1968, *78*)

3. The maintenance costs of post delineators can be either substantial, as in the case of northern states where large quantities must frequently be replaced, or nominal in dry southern states. In the Arizona study, post-mounted delineator plates were recommended over edge striping because of the low maintenance compared to striping. (Arizona, 1963, *41*)

4. Illinois reported that the first annual washing of 20,000 delineators and mile markers of the entire 187-mile Illinois Toll Highway system was accomplished in 12 days and at a cost of only $3.24 per mile. (Illinois, 1966, *30*)

5. Prior to 1963 Colorado used wood posts for their delineators because they were cheaper than the metal posts. However, the cost situation has reversed and they are now using metal posts. The wood posts are still evident in some areas. (Colorado, 1969, B)

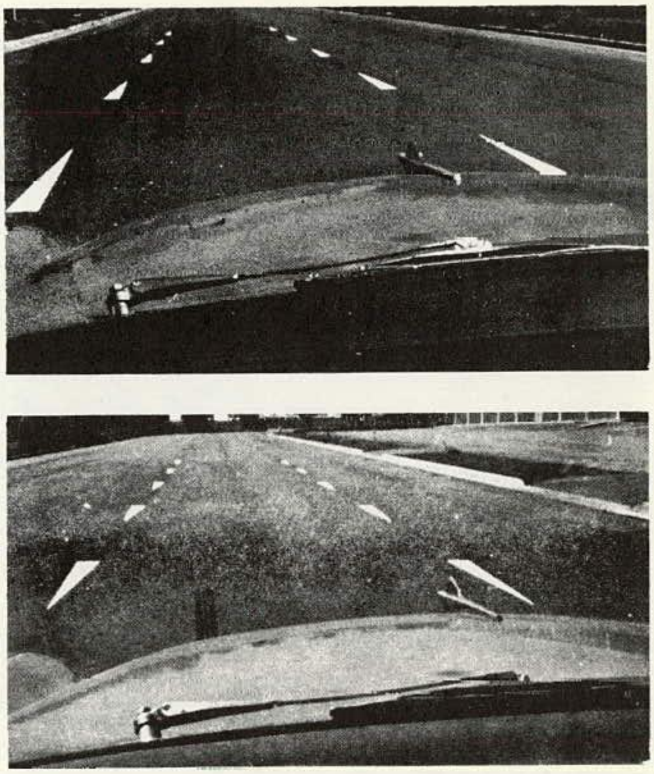

Figure C-3. Tucker pyramidal markings as seen by driver in center lane of three-lane roadway: upper, when traveling in right direction; lower, when traveling in wrong direction.

Environmental Effects

1. During the day, post delineators are of little use in the form of delineation and, indeed, the "paddle" type has been criticized for its unaesthetic appearance. (E) (See Fig. C-4.)

2. Delineators become ineffective at night when placed under a constant pole-mounted light source. High-level illumination tends to wash out the reflectivity and, therefore, post delineators are not recommended for use on continuous lighted sections of the highway. (E)

3. The reflector effectiveness is reduced when there is a coating of road film or water. A study at Texas Transportation Institute indicated that reflective delineators mounted on a channelization curb lost about 75 percent of their reflectivity when subjected for an extended period to slow drizzle and rain (TTI, 1963, *14*). This substantial reduction is probably explained by their closeness to the pavement. (See Appendix J for a discussion of visibility and reflectivity of reflector devices.)

Other Comments

It appears that no significant physical changes to the standard post delineators are required. Some manufacturers have considered varying the shape of delineators for special purposes—such as a spherical delineator that could be viewed from any angle.

Figure C-4. Post delineator with "paddle," California.
See C-5 below

1. A diamond-shape delineator (reflective sheeting, 4×4 in. and 12×12 in.) is being used in New York. (E)

2. At several curves on the Pennsylvania Turnpike post delineators in the shape of curved arrows are used to highlight the presence of a curve (Fig. C-5). (E)

3. Special reflective delineators for guardrails and/or bridge railings have been introduced recently. One type, observed in Pennsylvania and North Carolina, consists of a bracket to hold rectangular or round delineators to bridge railings. A second type of bracket holding a standard round reflective disk is bolted to the guardrail at support posts (Florida, 1969, B). California uses a similar type, called "lollipops," on some guardrails (note guardrail in Fig. C-4). Another type has a rhombic shape, also bolted to the guardrail (North Carolina, 1969, B). Still another type, used experimentally in Michigan, is trapezoidal in shape, with reflective tape providing the reflectivity. Small rectangular bracket-type delineators for use on guardrails were also observed in Colorado.

4. In winter, Colorado attaches wooden range rods to their delineator posts. These rods extend approximately 4 ft above the delineator post and indicate the location of the delineators for the snowplow operators. (Colorado, 1969, B)

Synthesis and Evaluation

Post delineators of various forms have gained wide acceptance throughout the U.S. This is undoubtedly due to their delineation effectiveness during nighttime and especially during inclement weather, when normal pavement markings are ineffective.

Colored delineators have been installed on exit and

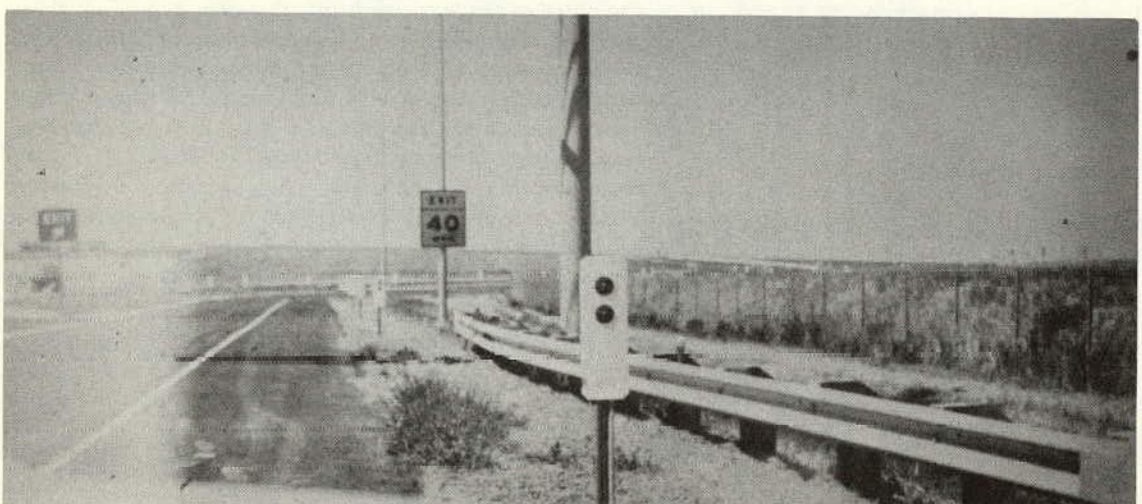

Figure C-5. Curve-shaped post delineator, Pennsylvania Turnpike.
See C-4 above

entrance ramps and at other complex sitautions. Although colored delineators are lower in reflective brightness than the clear ones, their contrasting colors offer the least likelihood of driver confusion at these situations.

Post delineators can cost from $74 to $145 per mile, which compares favorably with a reported average of $115 per mile of 4-in. standard paint stripe. However, post delineators are recommended as a supplement to, and not a replacement for, standard paint lines.

A significant maintenance problem is keeping the reflective delineator clean of road dirt. Delineators define the vehicle path more effectively when placed lower to the ground, for they are then associated directly with the roadway. However, the road film quickly covers the delineators and reduces their reflectivity when placed lower than the standard 4 ft. Replacement of damaged delineators and/or posts is a major maintenance item, particularly in heavy snow areas, as many posts are bent over by the snow banks pushed up by the plows.

RAISED PAVEMENT MARKERS

Raised pavement markers were used as early as 1936. "Catseye" road studs, used extensively in England, were installed in large numbers in the 1940's. The forerunners of the types of markers used today in the United States appeared about 1954 (in California).

Markers are still in the developmental stage, but most of the snow-free states have installed at least a few test sections; California has installed several million markers. At least two firms are engaged in the development of a marker that will withstand snowplowing.

Materials

Markers are quite varied, as they are produced by several manufacturers. Several types are shown in Figure C-6. In general, the size, shape, and material used are chosen to fulfill the delineation requirements at the lowest cost. Usually, there are trade-off points where one can achieve greater visibility at a higher cost or a lower visibility at a lower cost. This is not a linear relationship, however, and the markers selected should be chosen on the basis of the site delineation requirements.

Markers are reflectorized, non-reflectorized, or exhibit these characteristics together on a single marker. (The combinations designed thus far have been disappointing; in general, they are relatively poor both during daytime and nighttime as compared with the corresponding single-purpose markers.)

The most popular nighttime reflectors are made of plastic material with either cube-corner reflex units or glass inserts of various shapes. Sometimes the reflex units are placed in a special housing, such as the steel ramp-type developed by Stimsonite or the high-impact plastic/rubber housing by Traffic Standard, Inc., for use in areas where snowplows damage other types of markers.

Ceramic markers are very durable and are used extensively for daytime delineation. However, their nighttime reflectivity is not sufficient for most applications.

Special environmental conditions. such as dense fog, sometimes require lighting supplemental to the reflection gained from the vehicle's headlights; in these cases, low-voltage electric lights have been used. These are similar to the lights used along airport runways.

In an attempt to reduce initial cost, markers are sometimes formed from the same material as the roadway: for example, portland cement concrete may be formed into raised markers; the concrete may be grooved while setting to form depressions; or the concrete may be poured into a grid that has metallic reflecting crossbars. Sometimes the reflective delineation has been incidental, such as with bituminous hot-mix material used for rumble strips, where the reflection is produced by the various plane surfaces and shadows.

An acrylic cube-corner reflective unit encased in a plastic shell is the most popular nighttime marker at present. The Stimsonite "88" is an example of this type (Fig. C-7). Another popular type is the low-reflectivity markers, made by Safety Guide (Fig. C-8), American Clay Forming, and Stimsonite (Model "89"). (California, 1966, *42;* California, 1968, *53;* Washington, 1967, *60, 98;* Louisiana, 1967, *51*)

Southwest Research Institute has made and placed a raised reflectorized marker in one operation. The $4 \times 2 \times 0.145$-in. marker was made of pigmented epoxy and 19 glass beads of 0.25-in. diameter (Fig. C-9). Markers were applied and the white center skip line was repainted at the same time. Curing took 15 minutes. (SRI, 1967, *48*)

Convex reflective buttons consisting of thousands of glass beads suspended in a flexible polyester resin binder and titanium dioxide or lead chromate pigment are used widely. Examples are "Botts-Dots" and "Catadots." (California, 1966, *70, 15;* Louisiana, 1967, *51;* California, 1967, *37*)

Wedge-shaped one-way and two-way plain white non-beaded and beaded markers have been used to replace or supplement 100 miles of white stripe in California. (California, 1966, *42*)

Precast plastic buttons were used in an Arkansas experiment. The button, kept at 275° F, is pressed onto heated pavement (180° F) after epoxy has been applied to both the button and the spot. (Arkansas, 1965, *88*)

California uses ceramic markers (Fig. C-10) for daytime visibility because long, hot, dry periods produce staining in the polyester markers. (California, 1968, *53*)

Ceramic markers are frequently placed on a ⅛-in.-thick butyl pad to simulate a yielding underbase. (California, 1968, *53*)

Tapered, hardened steel castings containing two reflective plastic inserts have been used experimentally in Pennsylvania for two years on the Schuylkill Expressway, which must be snowplowed (see Fig. C-11). These markers, developed by Stimsonite, are set in grooves cut into the pavement and held in place by epoxy adhesive. New Jersey is also experimenting with these markers. Although they have been successful as lane markers, especially during night and rainy weather, they have not yet proved to be durable. (Pennsylvania, 1969, *92;* New Jersey, 1967, C)

Traffic Standard, Inc., has also developed a marker to be used in areas requiring snowplowing. These markers

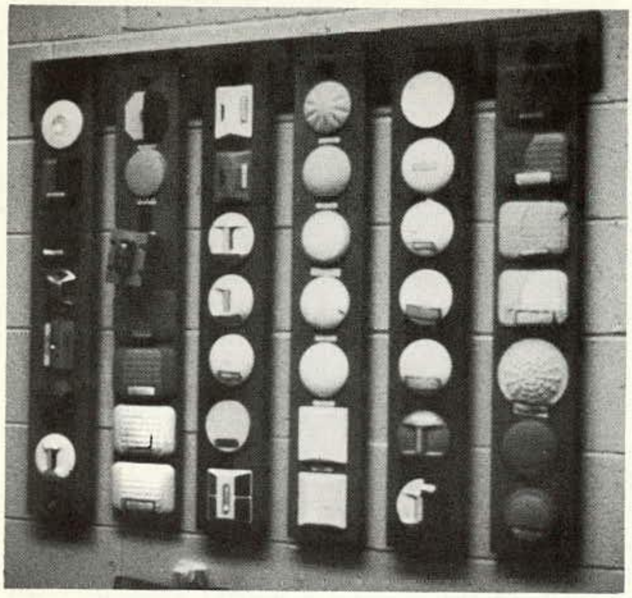

Figure C-6. Display of raised pavement markers.

consist of reflective units placed in a drilled hole in the pavement (see Fig. C-12). Termed "Kone-Lites," these units incorporate a self-wiping feature that operates when the reflective unit is depressed by traffic, similar to the wiping action of the English "Catseye." A few of these units have been installed in New Jersey, but evaluation is not yet complete. (D)

The English "Catseye," one of the first reflective raised markers developed, is still very popular in England. It incorporates a self-cleaning feature, and it is reported the markers can withstand snowplowing if rubber-bladed plows are used. Again, these are installed in the pavement, rather than being attached to the pavement surface. See Appendix D for more details on these markers. (C)

Currently, California uses the following types of raised pavement markers:

A—non-reflective white markers.
AY—non-reflective yellow markers.
B—2-way clear reflective markers.
C—red-clear reflective markers.
D—2-way yellow reflective markers.

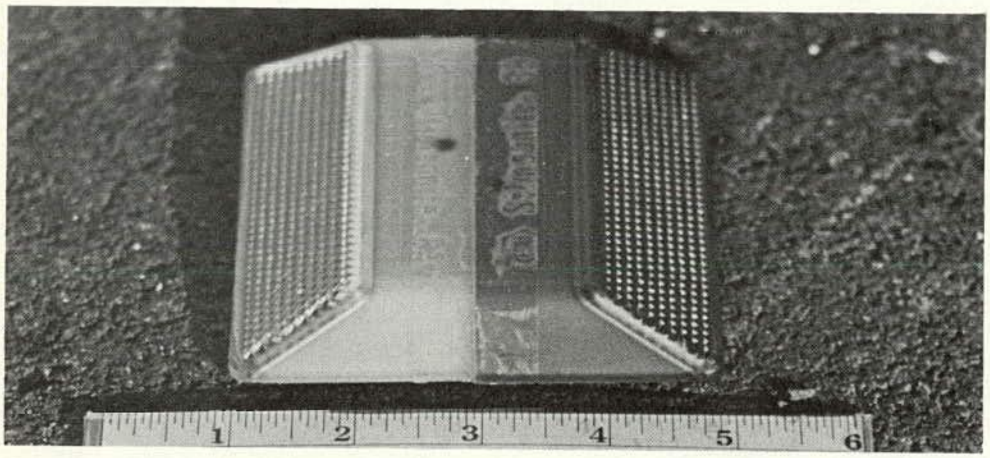

Figure C-7. High-reflectivity marker—Stimsonite.

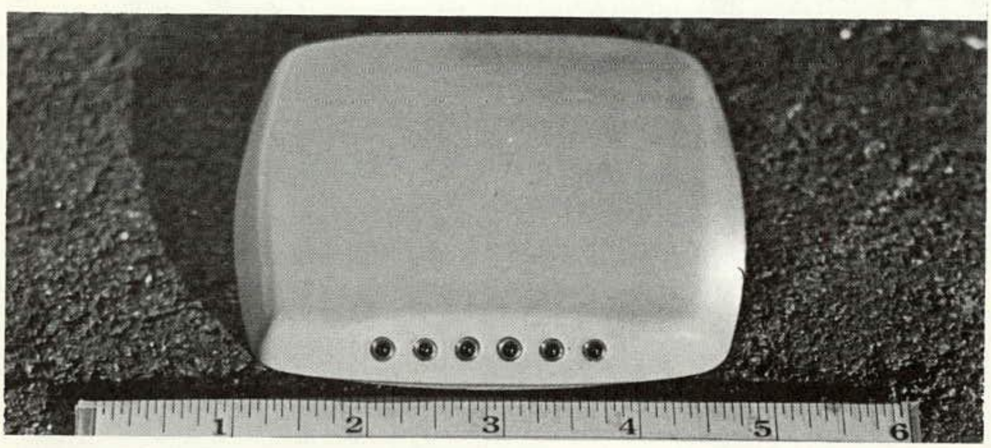

Figure C-8. Low-reflectivity marker—Safety Guide.

G—1-way clear reflective markers.
H—1-way yellow reflective markers.

Furthermore, the non-reflective markers (A and AY) are classed:

Class II—polyester binder type for use only on asphaltic concrete.
Class III—ceramic type for use on portland cement and asphaltic concrete.
Class IV—ceramic type for use only on portland cement concrete.

Curb marker lights: Twelve-volt, 5-w bulbs, 5 in. o.d. by ¾ in. high are placed in two-piece watertight brass fixtures. Wiring is placed in plastic conduits located alongside the curbing. Each is wired individually. The system is arranged for multiple operation from 240-v mains. Markers are cemented to the top of the curb. (ITTE, 1962, *50*)

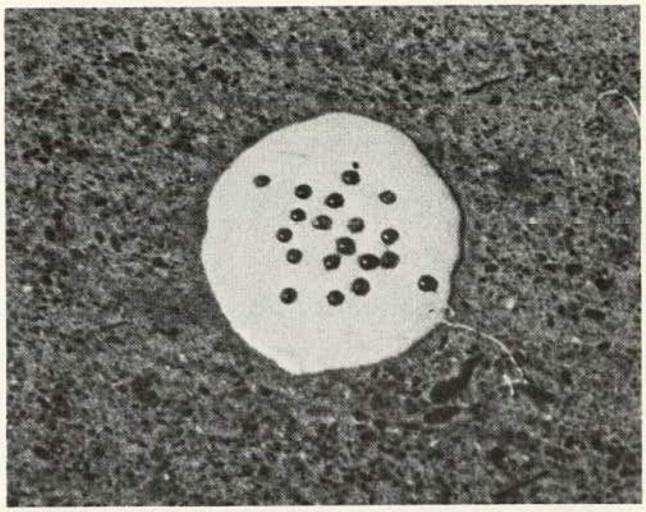

Figure C-9. Epoxy marker developed by Southwest Research Institute under NCHRP Project 5-5.

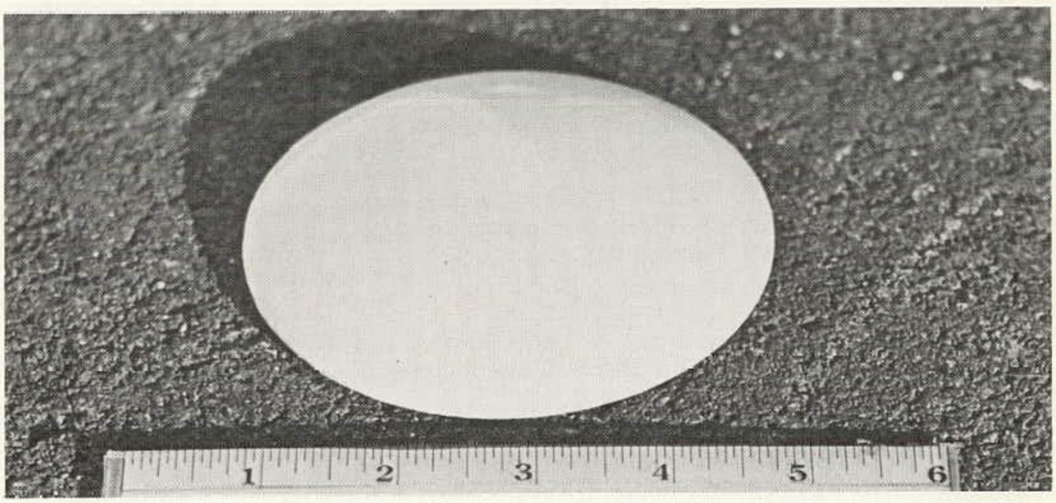

Figure C-10. Ceramic daytime marker.

Filament light markers: Small, flat, circular, disc-shaped fixtures; the 3-w size is adequate and preferred for roadway use, but other sizes are available. The bulb is located in an open top. (In clear weather, 5 w at 14 v is too bright; suggest 8½ v in clear weather and 14 v in cloudy.) (ITTE, 1959, *27*)

Reflecting surfaces have been created by grooving or embossing concrete while it was setting; casting in concrete, porcelain, or metal; and pouring cement into a grid that had metallic crossbars to act as reflectors. (Bingham, *57*)

Rumble strips made of bituminous hot-mix material serve also as reflective markers. (Illinois, 1954, *73*)

On the Golden Gate Bridge a plastic tube 20 in. long and 5 in. in diameter is attached to the pavement by means of removable steel pins. The tubes are placed and changed

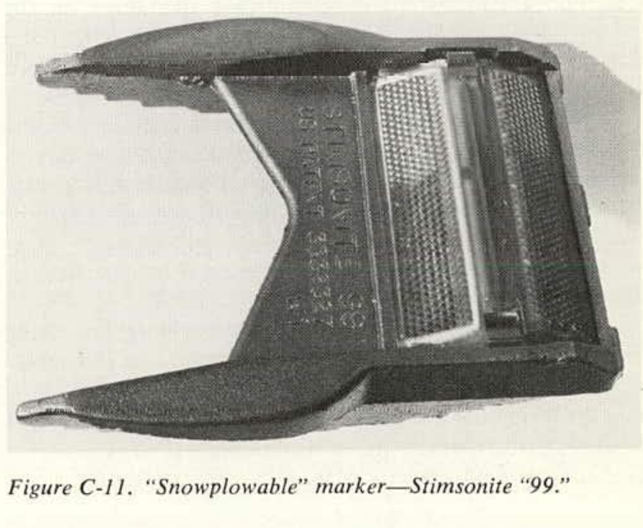

Figure C-11. "Snowplowable" marker—Stimsonite "99."

Figure C-12. "Snowplowable" marker—Traffic Standard "Kone-Lite."

by hand, for lane reversal, using a special-purpose truck. (California, 1965, C)

Maintenance

The more recently developed markers appear to be quite strong and resistant to damage. Many have a predicted life of ten or more years. Damage does occur to individual markers and these are replaced, but the replacement can be done at the convenience of the maintenance department because the loss of one or two does not upset the effectiveness of the marking system. (Washington, 1967, *60*)

Most markers are attached by epoxy adhesive, but some are bolted; the snowplowable type are generally set into the pavement. They can be attached to asphaltic concrete pavements or portland cement concretes. The pavement must be clean and usually is sandblasted to remove dirt, oil, and grease before attaching. Temperature is important—the higher the temperature the faster the setting. The epoxy adhesives are very strong and generally the removal of a marker will damage the concrete (the bond is stronger than the concrete). Special equipment has been designed to facilitate installation of markers.

Snow removal presents special problems because the snowplow's blades tear the markers loose. Several groups are working to solve this problem. Southwest Research Institute has developed a raised pavement marker with a low profile that they believe should be less subject to snowplow damage and also not require removal for resurfacing. (SRI, 1967, *48*)

Spring-loaded and rubber-edge plow blades are being tried, but chemical snow removal seems to be the better solution in areas of light snowfall. (Washington, 1967, *60*) Washington has also experimented with snowplows with a polyurethane edge. (Washington, 1969, C)

As mentioned under "Materials," special markers are being designed to withstand the snowplow blade. Stimsonite's marker (a reflex unit in a steel casing) is being tested in Pennsylvania and New Jersey. A few of the Traffic Standard, Inc., markers (a reflective unit placed in a plastic/rubber housing) have been installed in New Jersey to test their durability. (D)

The use of raised pavement markers on two-lane roads is not widespread. Even though the life of the markers being used is assumed to be only three years, it is being found unfeasible to apply them to a very large percentage of the two-lane mileage because within that three-year period they would be destroyed by surface treatments. The estimated life of non-reflectorized markers is at least ten years. Thus, it appears doubtful that a program can ever be undertaken to replace paint on two-lane roads with raised pavement markers unless methods are developed for sealing and resurfacing around them. (California, 1969, B; Texas, 1969, B)

Most markers are self-cleaning, requiring only tire action and moisture. When long periods of drought occur, or when the markers are placed on curbs (where tire action is not possible), the markers are not cleansed and films build up to decrease their visibility. Opaque, hard, black film collects on downstream surfaces. Plastic markers (epoxy, melomine, polyester) collect dirt quicker than ceramic markers. (D)

Ceramic markers acquire tire markings and dirt, but clean up readily under tire action with as little as one hour of rainfall; loss of markers during a 50-month period was not noticeable, so those lost can be replaced at the convenience of the crew (vs a fixed schedule); four annual repaints were required in the test section. (Washington, 1967, *60*)

Reflectorized markers picked up traffic dirt and tire marks rapidly. Because of the slightly rough texture, the dirt held despite wet weather. (Washington, 1967, *60*)

The average life of the Stimsonite "88" markers used in California is about 3½ years. Actually, they may be good for better than 5 years under most conditions. The loss rate at weaving sections or other places where traffic is changing lanes consistently is quite high. (California, 1969, B) The service life depends on the quality of the asphaltic concrete and its cohesive strength in hot climatic areas. (California, 1966, *42*)

On asphaltic concrete pavements, the wedge marker is more durable than the button type. Impact of traffic is less likely to cause failure in cohesion of the asphaltic concrete under the marker. (California, 1966, *42*)

"Catseyes" deteriorate under traffic and were scratched and broken by the action of sand and small stone particles that traffic ground into the glass surfaces. Many were broken by traffic in a two-year study. (California, 1962, *43*)

California reports that, from their experience, raised pavement markers using large glass inserts are not satisfactory. All these types that they have tested failed due to splintering and cracking of the glass in a fairly short time. Those types using smaller glass beads fail because the glass beads chip out in a fairly short time. (California, 1969, B)

Studded tires, when new, damage all markers to some degree. Pitting is greater on ceramic markers; scratching is greater on reflective markers; a skidding studded tire gouges all markers. (California, 1968, *53*)

Abrasion is an important maintenance problem in desert areas, where blowing sand can erase brilliance in a short time. Abrasion also takes place in agricultural areas where dirt and dust are deposited. (D)

The maintenance cost, after installation costs have been paid, is about one-fourth that of painted stripe according to a Washington study. It is reported that 2.5 percent of the markers were lost in a 19-month test period; in 54 months, 15 percent. (Snow removal was not important because most snowfalls received snow chemicals.) (Washington, 1967, *60*)

Electric lights are new for roadways, so no data are given; however, maintenance operations are anticipated to be simple and not often required. Maintenance should be minimal because of (a) an easy-to-replace common light bulb; (b) good drainage—the units are above the roadway; (c) tire action prevents dirt collection; and (d) heat from the bulb may melt snow and ice. (ITTE, 1962, *50*)

Costs

The initial purchase and installation costs for raised pavement markers are quite high when compared with other kinds of delineation. However, once RPM's are placed and in operation, additional cost is minimal.

Markers cost about twice as much as paint during the first year, but the cost is about the same when averaged over a 10-year period. Considering maintenance alone, the annual cost per mile for markers is much lower. (Washington, 1967, *60*)

Installation costs for polyester markers average \$0.30 to \$0.50 per marker for labor and materials. Machine installation should reduce costs by at least 50 percent. (Louisiana, 1967, *51*)

California reports a cost of \$700 per lane mile to install the acrylic cube marker. (California, 1968, *53*)

Bidirectional two-color reflective markers cost 45 percent more than monodirectional markers. (California, 1969, B)

"Catseyes" cost \$6 per unit to install. (California, 1962, *43*)

Southwest Research Institute's raised, reflectorized markers ($4 \times 2 \times 0.145$ in., holding 19 beads 0.25 in. in diameter) cost \$0.069 each for raw materials. In a test section, they were made and applied at the same time the white center skip line was repainted. (SRI, 1967, *48*)

Electric light markers cost about \$1.00 per lineal foot per line to install. Costs include marker lights; wire, transformers, and other materials; labor; engineering; and inspection. (ITTE, 1962, *50*)

Environmental Effects

Most of the experimentation with raised pavement markings have been concerned with providing maximum visibility under adverse weather conditions. The ideal day/night all-weather marker has yet to be developed, and so a tradeoff is usually involved in the selection decision. Plastic reflective markers are placed primarily for use at night and during heavy rain. Ceramic markers are installed primarily for daytime use. Electric lights have been installed in areas where dense fog is prevalent.

Plain markers have greater visibility under dry daylight conditions. Reflective markers are relatively unaffected by rainfall. An individual marker can be lost without decreasing the effectiveness of the system. The rumble effect alerts drivers who drift. (California, 1966, *70*)

Experiments with a variety of plain, beaded, plain and beaded, button, and wedge markers showed:

1. The fully reflectorized markers (beaded) are ineffective for daylight delineation in clear and rainy weather, particularly on portland cement concrete. The glass beads scatter the sunlight, causing the markers to have a grayish cast that blends with the portland cement concrete coloration.
2. The fully beaded button marker is more effective in rainy weather at night than is the wedge marker.
3. The glass beads used in the reflective button or wedge markers should be of the high-index-of-refraction variety (1.90 minimum).
4. Under overhead lighting, or in the daytime, the non-beaded markers are more effective than the beaded type in both clear and rainy weather. (California, 1966, *42*)

Stimsonite Model 88 loses 75 percent of its brilliance during the first several months of heavy traffic, then reflectivity levels off and remains good for at least five years. (California, 1969, C)

Reflective edge markers are effective when used with reflective center line marking. Spacing of 40 ft is recommended (tested 40, 80, 120, and 160 ft), but longer spacings are recommended for divided roadways with low ambient lighting. (Louisiana, 1967, *51*)

Southwest Research Institute's raised reflectorized markers performed well on rainy nights—with excellent retroreflectivity—even though beads of the desired high refractive index could not be found. (SRI, 1967, *48*)

During daylight hours, there are some combinations of roadway alignment and sun angle that considerably diminish the visibility of the ceramic pavement markers—i.e., they are less visible than paint lines under similar conditions. They are, however, still visible—the situation is roughly equivalent to that of paint lines that need repainting. (E)

The brilliance of raised pavement markers at night is reduced in the presence of overhead illumination. This problem may be critical if "blue tunnels" are standardized for ramp delineation. (California, 1969, B)

Electric light markers, similar to those used on airport runways, were installed on a California roadway because the roadway frequently was covered with dense fog. A light system designed to provide "contour perception" was studied. Conclusions and remarks included:

1. Lights produce a ladder effect: intensities add together to form a much higher apparent brightness than each single source alone. This causes the pilot (or driver) to automatically concentrate on that area.
2. Flicker, or flash-by, was not objectionable at the recommended light intensities.

3. Glare is negligible.
4. Rumble exists at slow speeds, yet is not a driving hazard at high speeds. (ITTE, *50, 27*)

Other Comments

Ceramic markers are used in Texas for daytime visibility and retro-reflective markers are used for nighttime visibility; a search is under way for a universal day-night pavement marker. The standard pattern is six ceramic markers spaced at 3 ft to give a 15-ft stripe followed by a 25-ft gap, then six ceramic markers again. Two-faced (clear and red) reflective markers are used in the center of every other gap (80-ft spacing). (Texas, 1969, B and E)

California uses a 9-ft paint line with a 15-ft gap for dashed lines. When using raised pavement markers, they simulate the 9-ft line with four ceramic markers spaced at 3 ft. Reflective markers are usually set in alternate gaps, or at a spacing of 48 ft. (California, 1969, B)

Markers with vertical faces produce the best rumble effect. (California, 1969, C)

Raised pavement markers may encourage the driver to overdrive in fog and may be considered undesirable from that standpoint. (E)

When white reflectors and yellow reflectors are placed side by side, the colors appear to blend and the markers are difficult to distinguish. An approach to solving this problem was to stagger the lines so that whites and yellows did not appear side by side. However, this pattern became confusing on curves and needs further study. (California, 1969, B)

The public has responded favorably to the feel and sound experienced in crossing lines of raised pavement markers. Such markers may be helpful to the sleepy or careless driver and a preliminary study indicates that the markers substantially reduce unnecessary lane changing, which is a major source of traffic conflict on freeways. (California, 1969, B)

Synthesis and Evaluation

Raised pavement markers were developed to provide delineation over a wider range of environmental conditions than is possible with painted lines, primarily to provide delineation on wet rainy nights when paint lines are ineffective because they are covered with a thin water film. In addition, reflectorization of some of the markers has increased their visibility distance beyond that of standard paint lines.

There are many types and models of raised pavement markers; reflectorized and non-reflectorized. The most extensive installations to date have utilized cube corner reflex units encased in plastic for nighttime visibility and ceramic button-type markers for daytime visibility. Pavement lines are formed by using both reflectorized markers for nighttime and ceramic markers for daytime visibility. Efforts to develop a single marker with equivalent day and night visibility have been disappointing. Several traffic engineers, researchers, and manufacturers express the opinion that the cube corner reflectors are too bright. They believe that a closer spacing of less highly reflective raised pavement markers is preferable to the brighter markers at longer spacings.

Southwest Research Institute, under NCHRP Project 5-5, developed an inexpensive low-reflectivity marker that is manufactured and installed in a single operation. This marker was designed to increase delineation visibility distances on rainy nights. It appears that the goal was accomplished. Unfortunately, as in the case of the other types of raised pavement markers previously discussed, these markers are removed in snowplow operations.

At least two manufacturers, Stimsonite and Traffic Standard, Inc., are developing reflective markers for nighttime use in areas where snowplowing is expected. Test installations have been made, but evaluation is not yet complete. As might be expected, these markers are relatively more expensive than the other types. Also, they will have limited visibility during the day.

Another approach to the snowplow problem is to specify the use of rubber-edged snowplow blades. This has met with resistance from maintenance personnel, however, and there is considerable doubt whether this will be a satisfactory solution.

The need for resealing and resurfacing of non-PCC pavements has limited the installation of markers on these surfaces. In general, the useful life of the marker exceeds the resurfacing cycle. Hence, the markers must be amortized over a short period, removed and then reinstalled, or covered in some manner and then uncovered. No satisfactory solution to this problem has been found.

The initial investment in purchasing and installing raised pavement markers is considerably higher than that for a single painting operation. However, because the useful life of the pavement markers varies from three to ten years, depending on traffic factors, marker type, pavement type and condition, etc., and maintenance costs are relatively low, it is generally claimed that the costs are comparable in the long run.

Public reaction to raised pavement markers as a form of delineation has been favorable. Minor criticisms of "excessive brightness" and "rumble" have been noted, but the preponderance of comments received by the various highway departments has been enthusiastic.

Certain side effects from the use of raised pavement markers have been noted and deserve more attention. These include the rumble effect, possible over-driving in limited visibility conditions such as fog, and a tendency to reduce the number of lane changes.

Efforts to develop a single all-purpose marker and to make optimum use of available markers through proper spacing, effective use of colors and shapes, etc., continue.

COLORED PAVEMENTS

Colored pavements, as defined in this section, are limited to colors other than black and white to provide delineation information to drivers. By excluding the use of light-colored shoulders with portland cement pavements and dark-colored shoulders with asphaltic pavements in the colored pavement section, the material can be structured in the standard format chosen for this report. The concept of contrast, independent of color, is a human factors consideration that is discussed elsewhere in this report.

Materials

The two most common materials used for colored pavements are portland cement concrete with a color additive and a synthetic resin binder that has the basic properties of asphalt. In portland cement concrete, a wide range of colors is available, and shades of these colors can be obtained by the mix design:

1. Iron oxides, either of natural or synthetic origin, are used to obtain shades of red, yellow, black, brown, buff, or tan.
2. Fluctuations in the amount of water per batch will give variations in the intensity and shade of the resultant concrete.
3. Pigment should be at least of the same fineness as the cement. The finer the pigment the greater will be the coloring power. (Grant, 1956, *74*)

or following the placing of the pavement:

1. The coloring material used on the job is called *kimiko*. It is described as a chemical solution that penetrates the pores of the concrete and, through a chemical reaction, becomes a permanent part of the concrete. The color selected for the Cabrillo Freeway is a deep reddish brown. (California, 1949, *67*)
2. The coloring was obtained by adding 33 lb of red oxide to each batch after it was discharged from the trucks. (Tennessee, 1949, *89*)

Colored asphalt, which is not really asphalt but a synthetic binder, can be specified in almost any color. The binder is clear, so the color is determined by the pigment added. Material specifications have been adopted by several states, as follows:

1. State of Pennsylvania Specifications on Pigmented Synthetic Resin Wearing Course FJ-1.
2. State of Ohio, Department of Highways, Supplemental Specification T-138.
3. State of New York, Department of Highways, Specification on Colored Synthetic Binder Concrete.

Maintenance

The wear characteristics of the materials are not adversely affected by the addition of color.

Cook County has had a year's experience with colored asphalt on a 600-ft section of Edens Expressway and reports: "Wyton binder has properties similar to asphalt . . . we are confident that in the long run it will prove more economical in terms of longer wear on the surface. . . ." (Illinois, 1962, *86*)

"A characteristic of the colored mix was the elasticity and adhesiveness contributed by the Wyton binder." The ability to undergo stress and return to normal form will tend to eliminate, it is said, the washboarding that often occurs in bituminous surfaces at traffic signals and STOP signs. (Illinois, 1962, *99*) However, color retention is believed to be a serious problem.

"That lack of agreement about color usage (what color is to be used for what purpose) impedes the use of colored pavement; that the colors are not effective at night, fade quickly, or get smudged by tire marks and oil drippings; that the synthetic materials are hard to lay and horribly expensive (up to $100 a ton); and that motorists sometimes are confused by the pavement." (*Engineering News Record*, 1967, *46*)

"One of the most common problems with colored pavement, synthetic or concrete, is fading. First experiments with the material years ago showed that, after relatively little wear, the top surface of the pavement wore off, exposing the coarse aggregate. The manufacturers feel they know how to cure this problem." (*Engineering News Record*, 1967, *46*)

"It has been established that fine materials all passing the No. 8 screen will permit color retention of from 90 to 95 percent. The secret to better color condition is the use of white aggregate. The color fading is the result of employing aggregates that are too large. It has been found that stone retained on a No. 8 screen is too large to be satisfactory." (Neville, 1967, *96*)

"Velsical Chemical Co., Chicago, thinks that the answer to the problem is colored aggregate." (*Engineering News Record*, 1967, *46*)

Costs

Several studies have been reported on the cost of the materials, as follows:

1. The economics of the new method are still in their infancy, and sound comparative cost statistics are not yet available. It cost approximately $40 to $45 per ton for mixing and placement of the Chicago Avenue pavement. (Illinois, 1962, *99*)
2. The average cost of a color paving installation ranges from $1.50 to $3.00 per square yard, depending on size and type of installation. (Ohio, 1966, *87*)
3. Material costs delivered at the batch plant total approximately $46.80 per ton of colored mix produced. (Neville, 1967, *96*)
4. "They reported prices ranging from a high of $113 to a low of $49 a ton in place as compared to an average of $8 a ton for conventional asphaltic hot mix. The average cost, discounting where the manufacturers donated the materials, was $82 a ton." (*Engineering News Record*, 1967, *46*)
5. The cost estimates from the Neville Chemical Company are given in Table C-2.

Environmental Effects

Rain

The problems associated with painted lines under wet conditions exist also for colored pavements.

"In addition to fading, colored pavement is obliterated by snow, looks black or white when wet and at night." (*Engineering News Record*, 1967, *46*)

"The surfaces encountered in practice reflect preferen-

TABLE C-2

COMPARISON OF COSTS PER TON, PLAIN ASPHALTIC VS COLORED PAVING MIX

TYPE OF MIX	MATERIALS COST ($) AGGREGATE [a]	BINDER	PIGMENT	LABOR [b]	TOTAL	APPLICATION COST ($) HAULING	APPLICATION	TOTAL	PROFIT AND OVERHEAD ($) [c]	TOTAL COST ($)	COST IN PLACE ($/SQ YD)
Plain asphaltic	3.00	1.50	—	1.00	5.50	1.00	4.00	5.00	1.60	12.10	0.67 [d]
Colored paving	8.00	18.00	13.50	3.50	43.00	1.00	5.00	49.00	7.35	56.35	1.56

[a] Delivered. [b] Cleaning, mixing. [c] At 15 percent. [d] Coverage = 18 sq yd at usual 1-in. application thickness. [e] Coverage = 36 sq yd at usual ½-in. application thickness.

tially (i.e., they reflect more strongly in directions close to the direction of mirror reflection than in other directions), the reflection becoming more preferential as the angle of incidence increases. . . . When the surface is wet, preferential reflection becomes much more important and the visibility of white line markings is reduced, unless the surface texture of either the marking or the road is sufficient to break up the film of water." (Reid, 1961, *90*)

Night

Night visibility is still a problem, but at least one report indicates there may be a solution.

"The purpose of ascertaining the value of colored pavement as a traffic directional indicator was taken in West Germany. At night, the roadways are floodlit, with the colored pigments retaining their full intensity." (Germany, 1966, *107*)

Traffic

Prediction of age of colored pavement has not been studied well, but at least one report indicates accelerated aging test results.

"It has been shown that when the asphalt in a pavement has been reduced to a penetration of 30, it is very likely to become brittle and form cracks, and that when it has been reduced to a penetration of 20 it is virtually sure to crack. . . . Accelerated aging tests have been carried out on several synthetic resin samples and two asphalt samples by storing the bitumens in an oven in a closed can with a small pinhole in the lid." (See Tables C-3 and C-4.) (Neville, 1965, *87*)

Other Comments

Use of colored pavements has been tried for various delineation tasks, but they have not been evaluated in many places. The findings from those states that have reported on colored pavement are noted in Appendix A under the appropriate situation.

The only real purpose for using colored pavement is to give fast, sure directions to drivers; but there is no nationwide standard for color meaning and the result is chaotic.

Red has been used: (a) by St. Louis and North Carolina on shoulders to tell drivers to keep off; (b) by Delaware for turning lanes; (c) by Wisconsin for off-ramps and truck lanes; and (d) by New Jersey in a strip to warn of a STOP sign ahead. *Yellow* has been used: (a) by San Diego for a turn lane; (b) by New York City for bus stops and to delineate cross-over routes between through and local service roadways; and (c) by Chicago and Ohio for median strips. (*Engineering News Record,* 1967, *46*)

Orange has been used for exit ramps on the Florida Turnpike. (Florida, B)

Green has been used by Ohio for left-turn lanes. (Ohio, 1967, *16*)

At Fort Hamilton (Brooklyn, N.Y.) the Army applied colored bands or sections to roadways to warn motorists of intersections or reduced speed limits. *Yellow* was used to denote "slow"; *red,* "stop." (Brooklyn, 1959, *66*)

Red, green, and *amber* pavements have been constructed at a busy intersection north of Richmond. The intersection was paved red, identifying it as the area of potential traffic hazards; and the northbound lane beyond the intersection has a green pavement, indicating the area of safety. (Virginia, 1969, *65*)

It is reported that colored pavement helps to keep traffic moving and prevents accidents. On the other hand, at least two states reported that colored pavement confused drivers, who slammed on the brakes when they ran over it or swerved violently to make turns after avoiding the colored deceleration lane. (*Engineering News Record,* 1967, *46*)

Synthesis and Evaluation

The ability to produce a variety of colors in materials that match or exceed the wear and other physical properties of portland cement concrete and asphalt paving has been demonstrated. No particular maintenance problems exist with the material, but the color tends to fade. New mix designs and aggregate combinations proposed by the manufacturers are claimed to cure this problem. There is a lack of test results to verify or refute this claim, however.

The cost of the material is in the range of three to five times as expensive as asphalt. It is just a little more expensive to color portland cement concrete. Because the

TABLE C-3

EFFECT OF ACCELERATED AGING AT 275° F ON PENETRATION OF BITUMEN SAMPLES

TYPE OF BITUMEN	PENETRATION ORIG.	AFTER 1 WK	AFTER 2 WK	AFTER 3 WK	AFTER 5 WK	AFTER 8 WK	AFTER 12 WK	WKS TO REACH 30 PEN.
Syn resin	83	75	63	56	42	31	21	8½
Syn. resin	83	77	69	62	52	40	27	11
Asphalt [a]	81	64	46	38	27	21	15	5 [b]
Asphalt [a]	83	72	53	44	32	26	19	5½

[a] Straight reduced. [b] Adjustment made for the 2-point lower original penetration of this sample.

TABLE C-4

EFFECT OF ACCELERATED AGING AT 275°F ON THE SAYBOLT-FUROL VISCOSITY OF BITUMEN SAMPLES

TYPE OF BITUMEN	VISCOSITY ORIG.	AFTER 1 WK	AFTER 2 WK	AFTER 3 WK	AFTER 5 WK	AFTER 8 WK	AFTER 12 WK	AFTER 27 WK
Syn. resin	93	99	100	106	112	140	165	416
Syn. resin	100	109	131	117	119	155	215	428
Syn. resin	100	107	103	110	108	147	169	271
Syn. resin	198	133	104	105	98	120	150	248
Asphalt	177	193	299	353	422	645	2050	461
Asphalt	141	171	217	243	288	609	750	478

thickness of the asphalt layer can be in the order of ½ to ¾ in., the asphalt is more commonly used than the concrete.

Colored pavements face the same environmental problem associated with other flat surfaces, such as paint. They are obliterated by snow, disappear when covered by a film of water, and are ineffective at night.

The use of colored pavements as a delineation material raises two questions that are unique to this treatment. The first is the problem of transferring the desired concept through a basically two-dimensional presentation as opposed to the one-dimensional treatments drivers are familiar with; the second is the problem of creating sufficient visibility, contrast, and attention-arresting characteristics on an area basis. Little experimental work has been directed at the former question, but the preceding state-of-the-art summary reports studies aimed at determining the properties of the material.

A survey of state highway departments conducted by *Engineering News Record* in 1968 revealed that the concensus of state highway engineers was that the material problems have not yet been solved. They ranked the problems associated with colored pavement as follows:

1. The color retention is poor.
2. The effectiveness has not been demonstrated.
3. The cost is too high.
4. It does not provide nighttime delineation.
5. It is difficult to maintain.

These responses were non-structured in that no categories were provided for selecting the problem type. They do, in part, reflect the position of the respondent within the agency questioned. The respondent was more frequently the materials and construction engineer than the operations engineer. However, all of these items are statements of the two basic questions enumerated previously.

There are other questions that arise when colored pavement is considered as a delineation treatment. The definition of uniformity, and the benefits derived from the application of colored pavements in conformance with a uniform standard, are examples of such questions. These questions are subsets of the basic question of the treatment's ability to produce sufficient information transfer to meet the situation requirements outlined in Appendix A.

A subcommittee of the National Joint Committee on Uniform Traffic Control Devices has recently proposed an extension of the present definitions of color meaning to:

1. Red is to be used for stop.
2. White will be used for medial strips, shoulders, and for general delineation.
3. Green will designate through lanes.
4. Orange will mark deceleration lanes.
5. Yellow is to be used to define prohibited areas, such as gores and safety zones.

The selection of colors by the agencies currently and historically experimenting with colored pavement indicates that this code is not favored unanimously. An interesting question that has not been answered to date concerns the real benefits of uniformity and the optimum code if the benefits are significant.

It is not yet known what, if any, message is conveyed to the driver. It may just be an alerting or attention-attracting device independent of the color used, or it may be that different colors create different responses.

RUMBLE STRIPS

Rumble strips have been experimented with over the last 20 years and provide the driver with audible, tactile, and visual stimuli. A common application is the placement of coarse-textured pavement surfaces longitudinally along the roadway to define the edges of the traveled path. If the driver's visual cues are degraded through environmental conditions or missing because he has fallen asleep, it is intended that the audible and tactile stimuli will inform him that he has left the intended travel path.

Another fairly common application is the installation of transverse rumble strips preceding STOP signs, particularly those at rural intersections where additional cues are needed to warn the driver of the STOP sign.

Materials

There are three basic types of rumble strips—intermittent raised bituminous sections, series of spaced overlays of coarse texture, and scored strips of portland cement concrete. A fourth type, epoxy-mounted plastic panels, is under study. (North Carolina, 1969, B)

The intermittent bituminous sections have been used to help define the median area. It is reported that the spacing of the individual units and the vertical lift constitute the principal causes of vibration. Height of the section, side slope, and vehicular speed contribute to the degree of severity. (Illinois, 1954, *73*)

The series of spaced overlays that are usually used at stop approaches consist of large stone aggregate and some type of bonding material. Typical bonding materials include varieties of asphaltic mixtures and synthetic resins. (California, 1962, *52;* Minnesota, 1967, *12;* TTI, 1966, *34*)

Scored strips of portland cement concrete have been used to define the median and the edge of roadways. (California, 1969, B)

The plastic panel type (4 × 12 in. each) are attached to the pavement with epoxy to form transverse lines (on 4-ft centers) across the width of the traveled way. North Carolina, 1969, B)

Scored PCC has been used in Pennsylvania to define the median areas, providing both rumble and contrasting color with the asphaltic pavement. Flat sections are used where traffic may cross; triangular sections, where crossing is to be prevented (see Fig. C-13). This scored PCC treatment is also used to shadow left-turn slots and as channelization islands. (D)

Coarse-textured overlays are used on some gore strips in Texas to enhance their visibility during rain and to provide a rumble warning to drivers who stray onto the gore area (see Fig. C-14). Texas, 1969, B)

New Jersey developed a rumble strip pattern that produced optimum jolting and vibration rumble. This pattern involved 5 transverse strips spaced at 10 ft 5 in. (total, 41 ft 8 in.) followed by a space of 10 ft 5 in., then 19 strips spaced at 9 in. (total, 11 ft 6 in.) The strips were formed of epoxy cement and were 3 in. wide and ½ in. high. Based on the results of these tests it was concluded that the rumble strip rather than the rumble area was better suited from both maintenance and warning considerations. (New Jersey, 1969, *58*)

A rumble stripe developed by Christensen Diamond Service serves the dual purpose of a paint line and a rumble strip. Longitudinal grooves are cut into the pavement, then paint is applied. Utah has experimented with this technique, but only preliminary results are available. (For more details refer to "Pavement Markings" section of this appendix.)

Maintenance

Aggregate used in the overlay should be very hard so that it will not break or decompose from traffic wear.

Kermit and Hein reported that, after a year, 60 percent of the stones that were held with seal coal asphalts were lost due to high-speed traffic. However, there was no apparent loss of stones when polyester resin was used as the bonding agent. They predicted that these strips would have a useful life of five years. (California, 1962, *52*)

It was found that the strips required considerable maintenance and periodic patching when cationic asphalt emulsion was used as the bonding agent. Chemicals had to be used to remove snow and ice during the winter because snowplow blades damaged the strips. It is theorized that the use of epoxy resins would bring the amount of maintenance down to a reasonable level. (Minnesota, 1967, *12*)

Use of cold-application resins was found to be undesirable because of their extremely short effective life under traffic conditions. However, experiments with slurry seal mixtures proved them to be effective as a bonding material. (TTI, 1966, *34*)

In Illinois, rumble strips consisting of ½-in. aggregate bonded to the existing pavement with a bituminous mxiture were found to be relatively free of maintenance problems. (Illinois, 1968, *79*)

Periodic sweeping is required when PCC scored strips are used if they are to maintain their effectiveness. (D)

Costs

Rumble strips using polyester resins as the bonding agent can be installed for $2.00 per sq yd. This results in a cost of about $1,000 for both sides of a four-way intersection. (California, 1962, *52*)

The use of scored strips of PCC could be justified economically only when they were installed in new construction. It was also thought that hot polyester resins could not be justified because of their costs and the special equipment needed to apply them. (TTI, 1966, *34*)

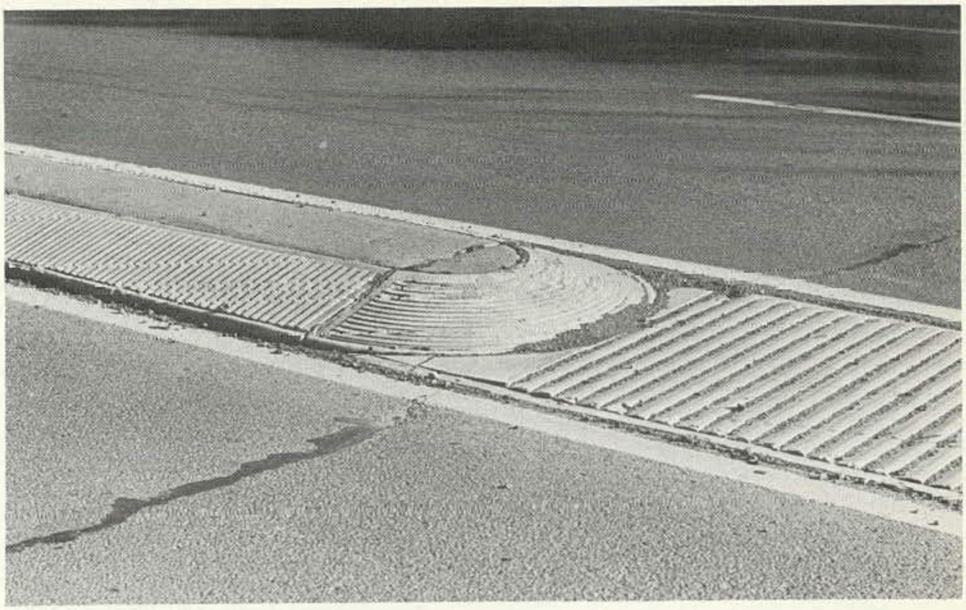

Figure C-13. Scored PCC rumble strips, Pennsylvania.

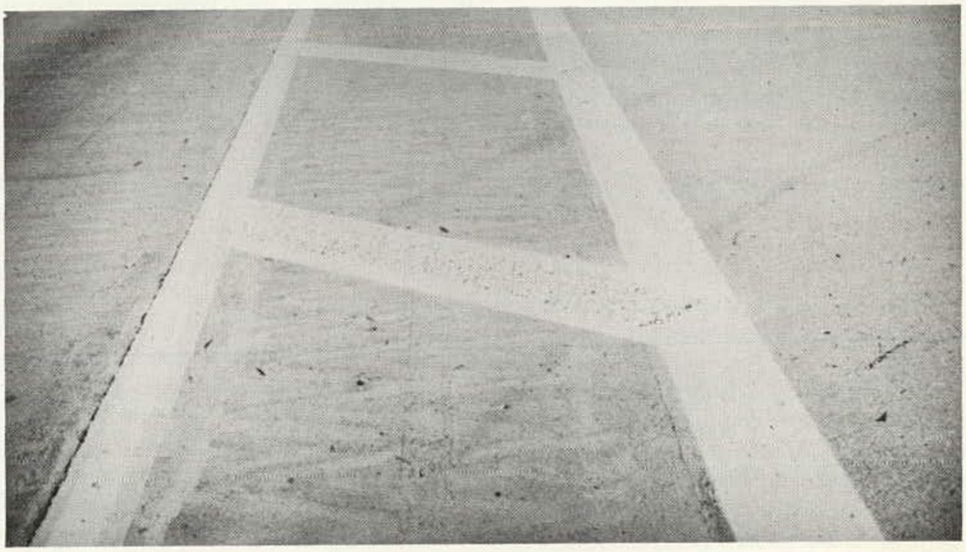

Figure C-14. Coarse-aggregate textured rumble strips, Texas.

The cost of PCC scored strips for median and edge delineation may be prohibitive. (California, 1969, B)

Environmental Effects

In thick fogs, a marking that generates a noise or vibration when a vehicle runs on it is helpful. (Great Britain, 1963, *59*)

Other Comments

With raised bituminous markers it was found that a satisfactory vibration was obtained when a spacing closely equaling the wheelbase length of an auto, in combination with sufficient height of the marker, was used. Special recommendations included: (a) 12.5-ft center-to-center spacing of the markers, (b) a 1-in. marker height, and (c) that the markers be placed normal to the center line of the road. (Illinois, 1954, *73*)

Decisions as to length of the strips and spacing between strips should be based on audible sound obtained from the strip pattern. Both the frequency and the intensity of the sound should increase as the speed increases. (California, 1962, *52*). California is experimenting with various shapes of raised pavement markers to increase their rumble effect. Their intended use is primarily for edgelines; the experiments are in a very early stage at this time. (California, 1969, *B*)

Rumble strips are used extensively on the edges of urban freeways in Houston, Texas. They are not used much in rural areas. Cost seems to be the major constraint on their further use. (Texas, 1969, B)

Use of epoxy resins as bonding agents should provide a substantial reduction in the amount of maintenance required for the coarse-aggregate strips. (Minnesota, 1967, *91*)

Studies are already under way to assess the effect of pregrooving portland cement concrete slabs longitudinally with patterns impressed in the unset concrete. This method might even be applicable to new or old asphaltic pavements that are not too plastic. (California, 1969, B)

Transverse rumble has been successfully produced by stretching surplus deep-sea diving hose across the roadway. It has a marked tendency to alert drivers by sound and feel, and its appearance arouses their curiosity. (California, 1969, B)

Synthesis and Evaluation

Rumble strips are intended to alert the driver's visual, auditory, and tactile senses simultaneously. Research has shown that brake reaction time is faster with an audible stimulus than with a visual stimulus alone. Further reductions in reaction time have been noted when the stimulus is effective in more than one sense modality.

Most installations of rumble strips have been experimental to date. When placed longitudinally, they are used to both delineate and define the edges of the roadway. In addition to providing a rumble effect if the driver should stray from the roadway, they are more visible than regular traffic paint during inclement weather.

Transverse rumble strips are used primarily for warning; e.g., on the approach to an unexpected STOP sign. In this case, the vibration and noise provide additional stimuli to alert the driver to the impending hazard.

Maintenance requirements vary with the type of materials used for the rumble strips. PCC scored strips require little maintenance other than an occasional sweeping. So far, installation has been limited to new construction due to the high cost involved in scoring existing PCC pavements. Transverse strips of coarse-textured aggregates are relatively inexpensive to install. The maintenance required depends primarily on the type of bonding agent used. It is believed that use of epoxy resins should keep the maintenance of the rumble strips at a reasonable level; however, as equipment and procedures for their installation are not standardized, the installation of rumble strips is relatively expensive and their use has been limited to special situations.

CURBS

Curbs, as defined in this report, are low walls used on the edges of roadways and channelizing islands. They serve several purposes—drainage, obstruction marking, and delineation. Concrete curbs are shown in Figure C-15 (also note contrasting shoulder treatment, ceramic center line markers, edge line treatment, and post delineator paddles). (Arizona, 1969, B) Asphaltic concrete curbs, sometimes called "dikes," are shown in Figure C-16 (also note contrasting shoulder treatment, ceramic pavement markers, and delineator paddles). (California, 1969, B)

This section discusses not only curbs, but also some curb-mounted devices.

Materials

Plain curbs and dikes seem to be going out of favor because of cost and safety considerations. (California, 1969, B)

A prototype curb has been developed with a 45° sloped face from which small blocks project every 18 in. Although these blocks are not purposely reflectorized, they do reflect light from headlights at night. (British Road Research Laboratory, 1967, *104*)

Several types of flush curbs have been investigated. These include smooth and textured lines of light-colored material, vertical flaps, and retro-reflective systems. The main conclusion reached was that, for visibility purposes, it is desirable to use either an efficient reflective device or to have light-colored surfaces perpendicular to headlight beams. (British Road Research Laboratory, 1963, *59*)

Yellow-painted bituminous curbing is widely used for channelized intersections. The paint contains (premixed) glass beads (4 lb per gallon) and maintenance crews are instructed to drop on another 2 lb per gallon. In general, however, the retro-reflective characteristics obtained are less than desired. This is, in part, due to the angle of incidence of the headlight beam for curb parallel to the highway and partly because there is little wear to uncoat the premixed beads. (North Carolina, 1969, B)

A low-intensity, internally illuminated, curb-mounted raised delineator has been developed. This unit is 5 in. in diameter and has a bulb inside to project light. The unit is cemented on top of the curb over a cast-in-place junction box. (ITTE, 1962, *50*)

Reflectorized curbs, prismatic reflectors enclosed in a "tunnel," rectangular delineators, reflective sheeting, and low-intensity lights were compared for curb mounting. It was found that reflectorized curbs did not work well because their reflecting surface is essentially parallel to the light source (headlights). The other methods were much more visible. (TTI, 1966, *34*)

Maintenance

In England, an attempt was made to increase the visibility of curbs by adding rubber flaps. It was found that folded rubber flaps mounted in a flush curb were not durable, but that plain flaps were. It was believed that the flaps would be satisfactory if they could be replaced easily. (British Road Research Laboratory, 1963, *59*)

Low concrete curbs, resembling rumble strips, have a tendency to fill up with debris and become ineffective. (British Road Research Laboratory, 1963, *59*)

Curb-mounted internally illuminated delineators are easily maintained. The tops can be easily removed, exposing the bulb and wiring. There is no mention of how long the bulbs may be expected to last. (ITTE, 1962, *50*)

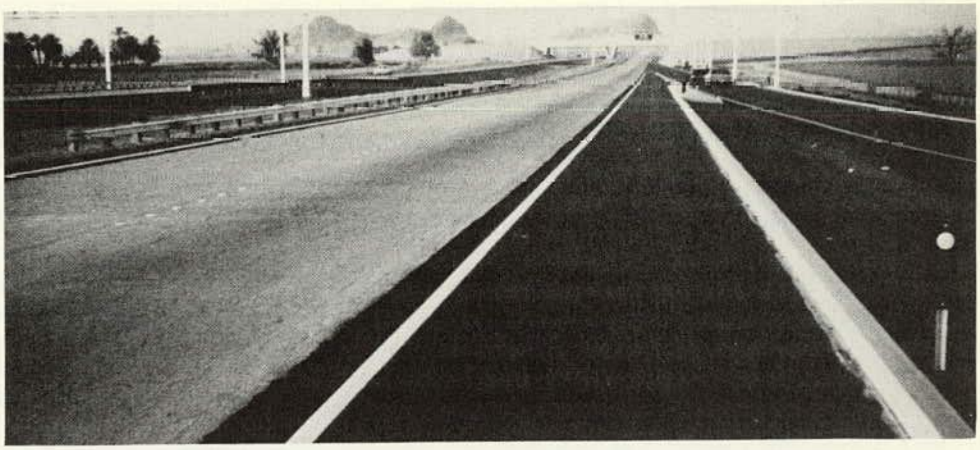

Figure C-15. Concrete curb, Arizona.

Figure C-16. Asphaltic concrete dike, California.

Low-intensity curb-mounted lights showed no tendency to accumulate dirt, even after one year. (TTI, 1966, *34*)

A special curb with a 45° face and projecting blocks (to reflect headlights) was found not to be affected by dirt. (British Road Research Laboratory, 1967, *104*)

Reflectors used on traffic island curbs require little maintenance in rural areas but have to be cleaned of road film coatings in urban areas, especially in inclement weather. (TTI, 1962, *14*)

Effectiveness of curb-mounted delineators depends on their being kept clean. (California, 1969, B)

Prismatic reflectors were enclosed in a horseshoe-shaped "tunnel" with vent holes in an attempt to make them self-cleaning. This was not entirely successful because they had to be cleaned about once a month in unfavorable areas and about every six months in cleaner areas. (TTI, 1966, *34*)

The extra cost of low-intensity lights is not justified if reflective devices can be made satisfactory through proper maintenance. (TTI, 1966, *34*)

Costs

Special curbs with projecting blocks have cost 5-15% more to make and 5% more to install because of the extra time and care required. (British Road Research Laboratory, 1967, *104*)

Low-intensity lights used experimentally on a California curb cost approximately $2.00 per linear foot (both sides); but the cost should be lower for more extensive installations. (ITTE, 1962, *50*)

Environmental Effects

Low-intensity lights were designed specifically for foggy areas. (ITTE, 1962, *50*)

A curb with projecting blocks is just as visible during the day as regular curb. At night, the blocks reflect light, in both dry and rainy conditions. The curb was not tested in fog or snow. (British Road Research Laboratory, 1967, *104*)

Flush curbs with protruding aggregate and smooth white lines and road paints tend to be obscured by rain. (British Road Research Laboratory, 1963, *59*)

Reflectors mounted on curbs lost approximately 30 percent of their reflectivity in three months of fairly dry weather. In light rain the reflectivity dropped 75 percent, but was partially restored by heavy rain. Factors involved are proximity of traffic, amount of dirt on the road, and volume of traffic. (TTI, 1962, *14*)

Rain makes unpainted curbs almost invisible at night. (California, 1969, B)

Synthesis and Evaluation

Plain curbs are not considered suitable for general delineation purposes due to high cost and limited visibility. A number of supplemental devices have been investigated, including flush curbs, flush curbs with vertical reflecting surfaces, curb-mounted reflectors, and low-intensity lights, to enhance the visibility of curbs installed for other purposes. The principal observation in these experiments was that delineating surfaces are most effective when placed perpendicular to the direction of travel.

Curbs find their primary application in urban areas—outside the scope of this study. In rural areas their primary use is for edging channelization islands. Here they provide strong negative delineation, and good visibility is important.

Until recently, California constructed dikes along rural freeways, but this practice has been dropped because it was believed that the expense was not justified and there is considerable doubt that the dikes enhance safety.

Because of their low placement, curb-mounted delineators are especially subject to accumulation of road film and dirt. Their effectiveness is dependent on the volume and proximity of traffic and on the environmental conditions. Low-intensity light units are probably affected the least by adverse environment conditions, but they are costly.

INDIRECT METHODS

Indirect methods are defined as any unit or system of units, either natural or man-made, that provides delineation to the driver but whose prime purpose is not for delineation. Indirect methods include such items as contrasting shoulders, lines of telephone poles running parallel to the roadway, guardrail, luminaires, advertising signs, and the road itself. Little material appears in the literature about delineation aspects of indirect methods. Most of the information appearing in this section was obtained from current practice interviews with officials of various state highway departments and observations of the project personnel.

In the following quote, Tutt and Nixon describe the role that the road itself plays in delineation. "Roadway delineation in daylight and good weather is actually accomplished by the fact that the road was built. Shaping the terrain into the proper position for vehicular travel in itself delineates the intended path. The color contrast resulting from the materials used often results in even further delineation." (Texas, 1969, *21*)

Although shoulder contrast provides excellent roadway edge definition during daylight (Fig. C-17) and on dry nights, it is reported that all effective color contrast between white and black pavement is lost on wet nights. This is true even in the situation where the PCC pavement is new and exceptionally white and the black shoulder is freshly sealed. (California, 1969, B)

"Sinopal" was used for lane delineation on the Pennsylvania Turnpike between the Harrisburg interchanges. It is reported that its wearability has been very good after about one year of service, and specular reflectivity along the shoulders has increased significantly. Sinopal from 5- to 8-mm size was spread in a 6-in. width using RC800 binder. The white aggregate provides color contrast with the pavement, and due to its rough texture the granules penetrate the water film and provide some delineation in rainy weather. Because Sinopal is being imported from Europe, the cost per ton is $35 at Baltimore or New York City. By manufacturing Sinopal domestically, the price should be reduced to about $25 per ton.

Michigan, particularly in urban areas where ramps are, of necessity, placed in close proximity, makes considerable deliberate use of contrasting materials; i.e., through lanes are PCC and ramps are black. (Michigan, 1969, B)

Guardrail is often an excellent source of delineation information and a number of methods have been employed to exploit this. Ordinary white paint is perhaps the most common; although it is not maximally effective at night, it is highly visible in the daytime. (E)

California believes that one of the secondary purposes of guardrail is to provide increased delineation on the edge of the highway. (California, 1968, *36*)

Reflectorization of guardrail is accomplished in a num-

Figure C-17. Contrasting shoulder treatment, Texas.

ber of ways. Long curved sections, often found on ramps, can be painted with 1 ft-wide bands of reflective paint (Fig. C-18) (North Carolina, 1969, B); the tops of guardrail posts can be painted with reflectorized paint (North Carolina, 1969, B, Montana, 1969, B; Florida, 1969, B); reflective delineators can be attached to the guardrail face at the posts (Florida, 1969 B,; Ohio, 1969, B; Colorado, 1969, B; California, 1969, B). (See Figure C-4.)

The increased use of Cor-Ten guardrail will tend to reduce the over-all delineation effectiveness unless supplementary reflectorization is provided.

Bridge rails are, albeit usually for shorter distances than guardrail, effective delineators when appropriately reflectorized. The same methods as used on guardrails have been applied here (Florida, 1969, B; North Carolina, 1969, B), and in one state an active research project is investigating the effectiveness of painting narrow bridges. (North Carolina, 1969, B)

Highway department officials in New Hampshire believed that the snowbanks created along the sides of the road by the plows provided drivers with a means of delineation. (New Hampshire, 1969, B)

In Montana, highway officials referred to a location where the motorists apparently used the telephone poles running parallel to the roadway as a means of delineation. A number of run-off-the-road accidents occurred when the road curved and the telephone poles continued in a straight line. (Montana, 1969, B)

Montana places cattle guards across the entrance and exit ramps to controlled-access highways. Driving across the cattle guard produces both a tactile and an auditory stimulus to the driver similar to the effect produced by a rumble strip. On exit ramps, the cattle guard encourages the driver to slow down before reaching the STOP sign at the end of the ramp. (Montana, 1969, E)

It was felt that headlight glare from approaching vehicles made it difficult for the driver to judge roadway alignment on two expressways in Chicago. Evergreen trees were temporarily placed in the medians of both roads. It was believed that, besides reducing glare, the trees provided the driver with a "third dimension," as opposed to standard roadways, which give the impression of having only two dimensions, length and width. (Illinois, 1966, *30*)

"Tower" lighting is being experimented with in Texas and some other states. This type of lighting illuminates the whole interchange area and simulates daytime visibility. However, because the illumination level is low and the light differs in character from sunlight, color contrast is considerably diminished. Also, if a driver does not use his headlights (not intended), the post delineators and most of the reflectorized signs are no longer visible. (Texas, 1969, B)

Other indirect methods include luminaires; advertising signs; cuts and gores in the topography; median barriers; and property fences, hedgerows, and tree lines running parallel to the roadway.

Synthesis and Evaluation

Indirect methods are a valuable supplement to standard delineation techniques. Most drivers probably unconsciously use these methods as they drive. However, it should be noted that indirect methods may produce undesirable effects as well as positive delineation. For instance, telephone poles and property fences may mislead drivers as to the roadway alignment ahead. This case usually occurs at a point where the poles or fences deviate from their previous parallel alignment with the roadway. (This problem is particularly severe in flat areas, where it has been necessary to use large target arrows, etc., to delineate these unexpected curves.) (Ohio, 1969, B)

Contrasting shoulders are sometimes used, either with or without painted edgelines, to enhance the visibility of the pavement edge. Sinopal has been used for a test installation along the Pennsylvania Turnpike, but the relatively high cost of this aggregate material has discouraged wider application. A new licensing agreement with a firm in the U.S. may reduce the cost considerably, as materials previously had to be imported from Europe.

Unfortunately, even though contrasting shoulders are

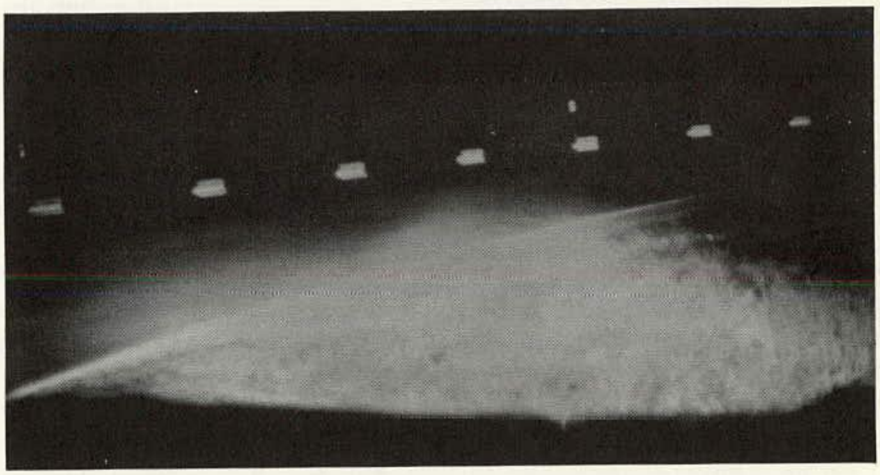

Figure C-18. Reflectorized paint on guardrail, North Carolina.

quite impressive during the daytime, and even on dry nights, most of the contrast is lost on rainy nights, when it is needed most; i.e., the effectiveness, from a visibility standpoint, under various environmental conditions is similar to that of painted lines. Hence, it seems that comparative evaluations must be made on the basis of cost, rather than visibility effectiveness.

As these indirect treatments have some primary purpose other than delineation, it is not likely that design and installation warrants from the delineation standpoint will be meaningful. The primary consideration in this area should be the elimination of misleading delineation.

SYSTEMS OF TREATMENTS

Inasmuch as systems are defined as collections of techniques and/or treatments applied to a site, any description of materials, environmental effects, maintenance, and costs would be repetitious.

Most "systems" work has been directed toward exit ramps. The standard color code, with few exceptions, is blue for exit, yellow for entrance, and white for through. One notable exception is the case of the split ramp, where the color is used to convey directional information—blue delineators and blue signing are used for one ramp and standard green signing and yellow delineators are used for the other. (North Carolina, 1969, B)

The system usually consists of color-coded edge lines, delineators, and signs; colored pavements may be included. Only a few studies have been made on systems of two or more adjacent interchanges; most have been on a single or problem interchange.

The results usually show no significant changes in speed, placement, headways, or accident experience. Most changes are in terms of fewer erratic movements and less confusion. Systems are most helpful at night and the biggest factor appears to be the amount of illumination. Public reaction is usually favorable.

APPENDIX D

DELINEATION PRACTICES IN OTHER COUNTRIES *

This appendix presents a brief summary of delineation practices in several other countries. Letters were sent to 21 countries and ECAFE (Economic Commission for Asia and the Far East) requesting copies of any published materials and/or manuals on delineation practices and for statements regarding particularly effective treatments, particularly difficult problems, and any experiments under way. In all, manuals from seven countries and the code on pavement markings in the ECAFE region were obtained. It was possible to derive some further information from literature in the United States that reported on practices in other countries, and from a limited amount of literature originating in other countries.

The material reported herein is significantly different in nature from that reported in Appendices A and C, which are devoted to practices in the United States. The material presented in this appendix was derived primarily from manuals, and, as such, represents primarily statements of standard practices in other countries, whereas the other portions of this report tend to emphasize new and/or unique practices on the assumption that the readers are familiar with the standard practices in the United States and with the *Manual on Uniform Traffic Control Devices.*

As a result of the literature survey, travels of project personnel, and interviews with visitors to and from European countries, it is believed that delineation receives relatively more attention in other countries. This is probably due to a number of factors, including:

1. There is generally more attention to maximizing utilization of the present road system, as opposed to building new facilities in these countries—right-of-way is generally at a premium and the ratio of construction/maintenance costs is probably much higher than in the United States.
2. Many of the presently used roads were laid out several years ago, so the geometric standards are not as high as on newer roads. Consequently, delineation must be relied on more heavily.
3. A larger proportion of the roadway is of the rural, two-lane type, as opposed to large expressway facilities. Because these two-lane roads are primary facilities, they receive more attention than the two-lane roadways in the United States.

Pavement markings, post delineators, and raised pavement markers are discussed in this appendix. No indication of the use of colored pavements has been found, and although it seems probable that rumble strips, curbs, contrasting shoulder treatments, etc., are used in other countries, no reports on these treatments were forthcoming.

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PAVEMENT MARKINGS

Legal Meaning of Pavement Markings

The legal meaning of pavement markings is discussed here from two standpoints—color and shape.

Color

The primary colors used for pavement markings are white and yellow, but red and blue are sometimes used in a supplemental manner. Black is used in several countries, but it is not considered a standard pavement marking color as it is used only to achieve contrast on light-colored pavements.

By definition, the colors have real meaning only in those countries that use two or more colors. The usual meaning assigned to the two main colors is as follows:

1. Yellow is used to attract the attention of drivers, indicating a dangerous situation, restriction, or prohibition.
2. White is used for normal guidance delineation.

A number of two-color system countries use yellow for edge lines and white for all other delineation. However, France provides the exception—reversing this concept and using white for edge lines and yellow for all other purposes.

The usual meaning of the supplemental colors is as follows:

1. Red for wrong way or parking restriction.
2. Blue for parking areas.

Shape

Shape is used for differentiation in the following manner: solid vs broken, double vs single, and broad vs narrow.

Solid vs Broken.—The usual meaning of solid vs broken is that solid lines are restrictive in character and broken lines are permissive in character. However, the degree of restriction indicated by a solid line is variable, and a slight restriction is implied even in broken lines.

In some cases, solid lines are used for no-passing lines and/or guide lines. There is no problem if double solid lines are used for no-passing zones. But if a single solid line is used, it is difficult to designate the difference between no-passing zone lines and guide lines (especially center lines), except when a two-color system is used. In many cases, single lines are used only for guide lines—having the meaning that the crossing of the line is to be discouraged, but not prohibited. Solid lines placed for this purpose include center lines, pavement edge lines, channelizing lines, and approach lines to obstructions.

Broken lines are usually used for guide lines or to distinguish between lanes that may be crossed at the discretion of the driver. Where broken lines are used, vehicles are permitted to cross the lines providing they do not interfere with other vehicles. There are some exceptional uses for broken lines—the "warning line" (England) and "safety line" (Germany). In certain geometric conditions drivers face the situation where the crossing of the line is dangerous but unavoidable. In such cases, a modified broken line (with the length of marked segment being either the same length as the gap or longer than the gap) provides an optical impression of an almost unbroken line so that the drivers tend to be very cautious in crossing these sections. This type is usually in single-color system countries to indicate that the crossing is permissive, but may be hazardous.

Combinations of solid and broken lines have differing meanings depending on which of them is adjacent to the lane in which the specific vehicle is traveling; i.e., the marking has the meaning of the solid line for the vehicles driving adjacent to the solid line, and it has the meaning of the broken line for the vehicles driving adjacent to the broken line.

Double vs Single.—In general, double lines are used to indicate maximum restriction. It seems to be universally accepted that double lines indicate greater restriction than single lines of the same width.

Broad vs Narrow.—Varying widths of lines are usually used to indicate the emphasis of either delineation or restriction. Especially in European countries, broad edge lines are used to emphasize pavement edge delineation. This practice is apparently based on two considerations. First, a broad side strip (not paint, but pavement materials contrasting with both the roadway and the shoulder) was used early in Germany for the Autobahns, and this example seems to have greatly influenced European marking practices. Second, some studies indicated that wide edge markings were even more valuable than center lines as safety features.

Stop lines are typical examples of restrictive meaning. Almost all countries use broad lines (12 to 20 in.) as stop lines.

As for wide longitudinal lines, some countries use wider lines as no-passing zone lines or warning zone lines to increase the emphasis of restriction.

Current Marking Practices and System Concepts

A summary of current marking practices in several countries is presented in Tables D-1 and D-2 and the following discussions. The tabulations indicate the application and/or meaning assigned to various types of lines in each of the countries from which adequate material was obtained.

Longitudinal Lines

Two major color systems are in use—single-color systems and two-color systems. In most countries, a two-color system (white and yellow) is used. Currently, no country uses color (yellow) for designating the direction of travel. The only use of color is for restriction (no passing, degree of safety, parking restriction) or the delineation of pavement edges.

Single-color system countries (white only) include England (uses solid yellow on curbs for parking restrictions, but this is not considered a main color), Germany, The Netherlands, and Sweden. No country uses yellow only.

Two-color system countries are divided into two groups. The first, using yellow for restriction, includes Finland (yellow for no-passing zones and center lines), Japan (yellow for no-passing markings only), and Switzerland

TABLE D-1

CURRENT PRACTICES IN USE OF LONGITUDINAL LINES IN OTHER COUNTRIES

COUNTRY	WHITE LINE SOLID	BROKEN	DOUBLE SOLID	DOUBLE BROKEN
Canada	• Center lines on: (a) Urban road with fewer than 4 lanes where passing is permitted but may be hazardous. (b) 4-Lane undivided urban road. (c) Restricted or hazardous section of urban streets. • Approach to intersection on urban streets.	• Center lines on: (a) Rural 2-lane road where passing is not normally hazardous. (b) Urban arterial streets with fewer than 4 lanes where passing is not normally hazardous. • Lane lines on both rural roads and urban streets.	• Center lines on: (a) 4- or more-lane undivided rural roads. (b) High-speed urban arterial streets with at least 2 lanes for one direction, or controlled-access urban highways. • Overlapped no-passing zone markings on 2-lane highway. • Pavement-width transition lines. • Approaches to intersection on rural roads (signalized).	• Center lines on urban streets with 4 lanes, but being operated as 2 lanes because of parking permission on each side.
England	• Pavement edge lines: (a) At particularly hazardous situations—e.g., sudden change of pavement width and on approaches to curves (4 in. wide). (b) On motorways (12 in. wide).	• Center lines on urban and rural road (18 ft, urban; 27 ft, rural). • Lane lines on urban and rural road (18 ft, urban; 27 ft, rural). • Pavement edge lines on urban and rural road (3-ft mark; 10.5-ft gap). • Warning lines (marked length is twice the gap length): (a) On urban and rural road where sight distance is limited, but is greater than the no-passing criterion. (b) At road junction, approach to central refuges.	• Overlapped no-passing zone markings. • Center lines over railway crossings.	
France	• Pavement edge lines (8 in. or 6 in. wide). (Edge marking acts as a guide and therefore is wider than the lane line.)	• Pavement edge lines (6 in. or 4 in. wide).		
Germany	• Center lines. • Pavement edge lines: (a) On freeway (2 ft 6 in. wide). (b) On other roads (1 ft 8 in. wide).	• Center lines. • Lane lines: freeway (30-ft mark; 30-ft gap; 6 in. wide); open highway wider than 24 ft (20-ft mark; 30-ft gap; 4 in. wide); other highway (20-ft mark; 20-ft gap; 4 in. wide). • Safety lines—to be used where the crossing of center line is dangerous but unavoidable (5-ft mark; 5-ft gap). • Separation lines of maneuvering sections (entrance or exit lanes, speed change lanes, 2 ft 6 in. wide).	• Overlapped no-passing zone lines.	
Finland	• Pavement edge lines. (Between traveled way and shoulder; roadway wider than 20 ft.)	• Center lines (roadway wider than 20 ft). • Lane lines.		
Israel	• Center lines (roadway wider than 20 ft). • No-passing zone lines (roadway wider than 20 ft).	• Lane lines (roadway wider than 20 ft).		
Italy	• Center line (no passing) on 2-way, 2-lane roads. Channelizing lane lines on approach to intersection. • Pavement-width transition lines (as the center line of pavement-width transition section).	• Center lines, on 2-way, 2-lane road (passing is permitted). • Lane lines (dimension of the line may change, depending on the situation—mostly variation in speed).	• Center lines: (a) On 4- or 6-lane undivided road. (b) On approach to intersection where the approach road is divided by solid lane line (channelizing line). • Overlapped no-passing zone lines.	

COMBINATION OF SOLID OR BROKEN	YELLOW LINE SOLID	BROKEN	DOUBLE SOLID	COMB. SOLID AND BROKEN
• No passing zone lines on 2- or 3-lane highway where the no-passing zone is in one direction. • Pavement-width transition lines. • Approaches to intersection on rural roads (signalized).	• Pavement edge lines. (To be used only on restricted or hazardous sections, such as an approach to a narrow bridge or sharp curve, on speed change lanes, on pavement-width transition sections, or where the shoulder has texture and color similar to the pavement.)			
• No-passing zone lines where sight distance is restricted in one direction (6 in. wide, 7 in. apart, 12-ft stud spacing).				
	• No-passing zone lines (4 in. wide).	• Center lines: 10-ft mark; 33-ft gap; 4 in. wide. • Lane lines: 20-ft mark; 30-ft gap; 4 in. or, preferably, 6 in. wide; or 16.7-ft mark; 33.3-ft gap; 4 in. or, preferably, 6 in. wide.		• No-passing zone lines: Restrictive from the solid-line side, permitted from the broken-line side.
• No-passing zone lines at the section where passing is permitted from broken-line side.				
	• No-passing zone lines. • Approach to an obstruction. • Roadway edge lines (between traveled way and bicycle lane).		• Overlapped no-passing zone lines.[a]	
	• Pavement edge lines (on asphaltic pavement wider than 17 ft).	• Pavement edge lines at access (on asphaltic pavement wider than 17 ft).		
• No-passing zone line on the section where no passing is in only one direction. • Approach to intersection (center lines).	• Pavement edge lines (as an edge line to delineate the effective roadway width). • Dividing lines (to divide emergency stop lane or bicycle lane from through lane).	• Border lines: (a) Between service station and through-traffic road. (b) Main road edge line across the merging point of minor road. • Delineation line at intersection. • Edge line to delineate bus stop.		

TABLE D-1 (*Continued*)

COUNTRY	WHITE LINE SOLID	BROKEN	DOUBLE SOLID	DOUBLE BROKEN
Japan	• Center lines on 4- or more-lane roads. • Lane lines. • Pavement edge lines. • Pavement-width transitions.[b]	• Center lines on 2-lane roads, and other roads where solid center lines are not provided. • Lane lines.		
The Netherlands	• Center lines at curved or gradient section on 2-way road (4 in. wide). • Pavement edge lines (6 in. wide).	• Center lines on 2-lane, 2-way road. • Lane lines on motorway.	• Center lines on 4 or more lanes, 2-way, undivided highway.	
South Africa	• Center lines on urban road where passing is not permitted. • Lane lines at the section where movement from one lane to another is to be prohibited. • Channelizing lanes (8 in. wide).	• Center lines on all paved 2-way roads wider than 16 ft. • Lane lines.		
Switzerland	• Safety lines (lines for separation).	• Center lines. • Lane lines. • Border lines on main road across the merging point of minor road.	• Safety lines (lines for separation).	
Sweden	• Edge lines on: (a) Rural motorway (6 in. wide). (b) Urban motorway (8-10 in. wide). (c) Urban road (3.2-4 in. wide). • Edge line to delineate cycle track or footpath (10 in. wide).	• Center lines on roads wider than 18 ft: (a) Rural—10-ft mark; 30-ft gap; 3.2 in. wide. (b) Urban—10-ft mark; 10-ft gap; 4 in. wide. (c) Motorway—10-ft mark; 20-ft gap; 4 in. wide. • Edge lines on rural road: 3.3-ft mark; 6.6-ft gap; 3.2-4 in. wide. • Maneuvering lines between speed-change lane and through lane: rural—4 in.; urban—6 in. wide.	• Overlapped no-passing zone lines (3.2 in. wide).	• No-passing zone lines. (Broken lines having larger marked segments—30-ft mark; 10-ft gap; 3.2 in. wide—are used as no-passing markings on roads wider than 25 ft.)

[a] Combination of solid yellow and broken white: Normal center line and 2 barrier lines are used at the location where sight distance is restricted.
[b] Combination of a solid yellow line and a broken white line may be used for no-passing zone markings. Combination of solid white and broken yellow is legally possible, but the practice does not exist.
[c] Combination of yellow and white. (Yellow lines had been used as center lines for a long time, but the yellow markings were replaced by white markings when Sweden changed the traffic system from left to right hand.)

(yellow for the approach to crosswalks). The second group, using yellow for delineating pavement edges, includes Canada, Israel, Italy, and South Africa.

Supplemental use of red and blue is made by the following:

Italy, blue for attended parking area; Switzerland, red to indicate parking restriction; and European Agreement on Road Marking, red or alternating red and white to indicate parking restriction.

System Concepts.—No country has a completely consistent delineation system. Usually the basic concepts of the system are mixed and confusing. In general, the system concepts in single-color system countries are more uniform than those in two-color system countries. The problem there, however, is that they must use a fairly complex code, based on different shapes of lines, because they are limited to a single color (e.g., different ratio of marks and gaps in broken lines and different widths in either solid or broken lines).

Differences in marking applications for single-color system countries include:

1. Separation of traffic flow in opposing directions. Broken lines are used by England and Sweden. Solid lines (no passing zones) and broken lines are used by Germany and The Netherlands.

2. Separation of traffic flow in the same direction. All countries use broken lines.

3. Difference in character between broken lines and solid lines. Broken lines are permissive in character and solid lines are restrictive in character in Germany and The Netherlands. Broken lines are used for separation of traffic flow and solid lines are used for delineating the roadway edge in England and Sweden.

4. Width of line. Width of line is used to indicate the degree of restriction in England and Germany; to indicate degree of edge delineation in The Netherlands and Sweden.

At present, no country uses color for separation of traffic exclusively. (This concept is included in the proposed revision of the U.S. MUTCD.) All the countries surveyed used line shape for separation of traffic; color is used to draw the attention of the driver (i.e., for designating the degree of safety).

	Yellow line			
Combination of solid or broken	Solid	Broken	Double solid	Comb. solid and broken
—[b]	• No-passing zone markings.[b]		• No-passing zone.	
	• Pavement edge lines. • Paved shoulder marking. • No-passing zone lines.			
(Being provided the same meaning as the European Agreement on Road Marking.)	• Outer edge lines for parking restriction at the approaches to pedestrian crossing.			
• No-passing zone lines where sight distance is restricted in one direction on roads wider than 18 ft (S.D., 530-800 ft). • Approach to intersection.	—[c]	—[c]	—[c]	—[c]

There are two major categories of two-color system countries, as follows:

1. Color for restriction (no-passing zone lines or parking restrictions), used in Finland, Japan, and Switzerland (and U.S.)
2. Color for pavement edge lines, used in Canada, Italy, Israel, and South Africa.

As mentioned previously, none of the countries surveyed has a completely consistent pavement marking system as regards line color and shape. However, the practices fall generally within two major groups, as follows:

Group I. Color is used to designate the degree of safety (a yellow line designates locations where it is unsafe to pass or change lanes); line shape is used to designate the direction of travel (a solid line to separate traffic streams moving in opposite directions, and a broken line to separate traffic streams moving in the same direction. Finland, Japan, Switzerland, and the U.S. are considered to fall in this group, although certain inconsistencies exist. For example there are different meanings for the same marking in that broken white lines are used for center lines or lane lines (Finland, Switzerland, U.S.), and different markings for the same meaning in that broken white lines are used for center lines of low-type roads (two-lane) and solid white lines are used for center lines of high-type roads (four lanes or more) (Japan).

Group II. Color is used to designate the roadway range (e.g., yellow lines to designate payment edges) and line shape is used to designate the direction of travel and/or the degree of safety. Examples of these are as follows:

(a) Line shape to designate direction of travel. A solid white line is used to separate traffic flow in opposite directions, a broken white line to separate traffic flow in the same direction (Israel).

(b) Line shape to define degree of safety. Solid white lines are used to designate areas where no passing or lane changing is permitted, broken white lines at all other locations (South Africa).

(c) Line shape to designate both direction of travel and degree of safety. Solid white lines are used to separate traffic flow in opposite directions for four or more lanes; a broken white line is used to separate traffic flow in opposite directions for two-lane roads; a broken white line is also used to separate traffic flow in the same direction; a solid white line is also used to designate areas where no passing or lane changing is permitted (Canada, Italy).

TABLE D-2

CURRENT PRACTICES IN USE OF TRANSVERSE LINES IN OTHER COUNTRIES

COUNTRY	WHITE LINE				YELLOW LINE	
	SOLID	BROKEN	DOUBLE SOLID	DOUBLE BROKEN	DOUBLE SOLID	ZIG-ZAG[a]
Canada	• Stop lines at intersection (12–24 in. wide).		• Stop lines at R.R. crossing (12 in. wide, 12 in. apart).			
England	• Stop lines at intersection controlled by traffic signal or police: (a) Urban—8 in. wide. (b) Rural—12 in. wide. • Stop lines at R.R. crossing (8 in. or 12 in. wide).	• Edge lines of major road at intersection (acts as transverse line for minor road).	• Stop lines at intersection controlled by STOP signs with worded STOP marking (8 in. wide, 12 in. apart).	• Give-way lines for minor roads at intersection with GIVE WAY signs and triangular give way approach.		
France					• Stop lines at intersection (8 in. wide, 4 in. apart).	• Stop lines at intersection.
Germany	• Stop lines at intersection (20 in. wide).					
Italy	• Stop lines at intersection (12 in. wide). • Stop lines at R.R. crossing (12 in. wide).					
Japan	• Stop lines at intersection (12 in. or 18 in., and 24 in. in special case). • Stop lines at R.R. crossing (12 in. or 18 in.).					
South Africa	• Stop lines at intersection: (a) Urban—at least 12 in. wide. (b) Rural—at least 18 in. wide. • Edge lines at intersection on major road (4 in. wide).	• Yield lines at yield-controlled intersection (24-in. mark; 12-in. gap). (a) Urban—at least 8 in. wide. (b) Rural—at least 12 in. wide.				
Sweden	• Stop lines at intersection (16 in. wide).	• Yield lines on minor road at intersection (16-in. mark; 16-in. gap; 16 in. wide).				

[a] Bars of equal length on alternate sides of a common transverse base line.

Transverse Lines

Transverse lines include stop lines at intersections, stop and/or yield lines at railroad crossings, yield lines at intersections to minor roads, and pedestrian crossings. Often, other supplemental treatments are needed in these locations, but the following observations can be derived from Tables D-1 and D-2:

1. All the countries surveyed use white as stop lines or yield lines except for France, which uses a zigzag yellow line as a stop line.
2. Stop lines are generally single broad solid lines (8 to 24 in.), double solid lines (8 to 12 in. wide), or double broken lines. In England, double broken lines are used as yield lines. Also, the European Agreement on Road Markings indicates that the double broken white lines should be installed where the YIELD sign is used.
3. The single broken line is not used as a stop line in any case. In England, the single broken line is used as the edge line for major roads where they cross minor roads.
4. The stop line alone is not sufficient; supplemental treatments are needed (no-passing center lines, supplemental word or symbol markings, signs).

Maneuvering Section Treatments

1. Markings at nose gores. Almost all the countries use chevron markings, slanted in the direction of traffic flow, at the approach to nose gores. "Conforming" lines (the lines used to outline the areas within which the chevron markings are contained) are usually solid white lines, but England uses a broken white line. The width and spacing of chevron markings and the width of the conforming lines are as follows:

COUNTRY	CHEVRON MARKING WIDTH (IN.)	CHEVRON MARKING SPACING (FT.)	CONFORMING LINE WIDTH
Canada	18-24	6	4.5-5.5
England	8	6	4
Japan	18	3.3	8

Only France uses yellow for these markings.

2. Lines between through lanes and speed change lanes. Canada and Italy use normal width lines (see Figs. D-1 and D-2). England uses a "warning line," wider than the normal lane line, with the marked length longer than the gap length (see Fig. D-3). Sweden uses the normal width (4 in.) broken line in rural areas, but wider lines (6 in.) for urban areas. Japan and Germany use broad broken lines (18 to 30 in. wide, 10- to 15-ft marks and gaps) (Figs. D-4, D-5, and D-6). The Netherlands uses special shapes (triangles, rectangular, or square panels) (Fig. D-7).

3. Length of line as related to length of speed change lane. Canada uses a line from the point where the full width of a speed change lane is obtained to the nose of the approach marking (see Fig. D-1). Italy, England, Japan, and Germany use the line throughout the length of the speed change lane (see Figs. D-2, D-3, D-5, and D-6).

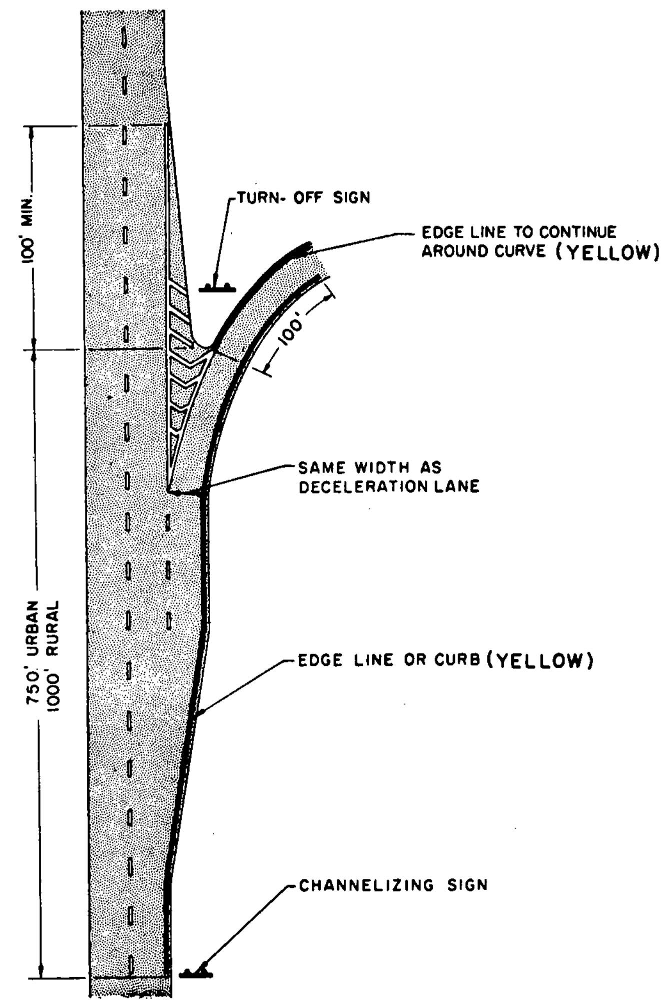

Figure D-1. Pavement markings, Canada.

Source: *Uniform Traffic Control Devices Manual*, Canada, May 1966, Fig. 28.

It is reported that drivers are hesitant to cross the wider lines (some are 30 in. wide, for instance) with the result that traffic leaves the through lane closer to the gore area. Also, the wider lines may be slippery. On the other hand, if the width is the same as for the standard lane lines, the drivers cannot distinguish the maneuvering situation as readily.

4. Use of edge lines at maneuvering sections. Almost all the countries continue the solid line of the through road along the edge of the speed change lane. In Canada, the edge lines are provided only at dangerous or complex situations. Hence, there are no edge lines along through roadways except in the areas adjacent to speed change lanes. A solid yellow line is used on the 750 ft (urban) or 1,000 ft (rural) preceding the nose gore and 100 ft after the nose gore along the outer edge of deceleration lanes and also along the inner edge of the off-ramp (see Fig. D-1). At acceleration lanes, the line is used only along the outer edge of the speed change lane and just 50 ft beyond the end of the taper.

5. Supplemental treatments. Supplemental treatments

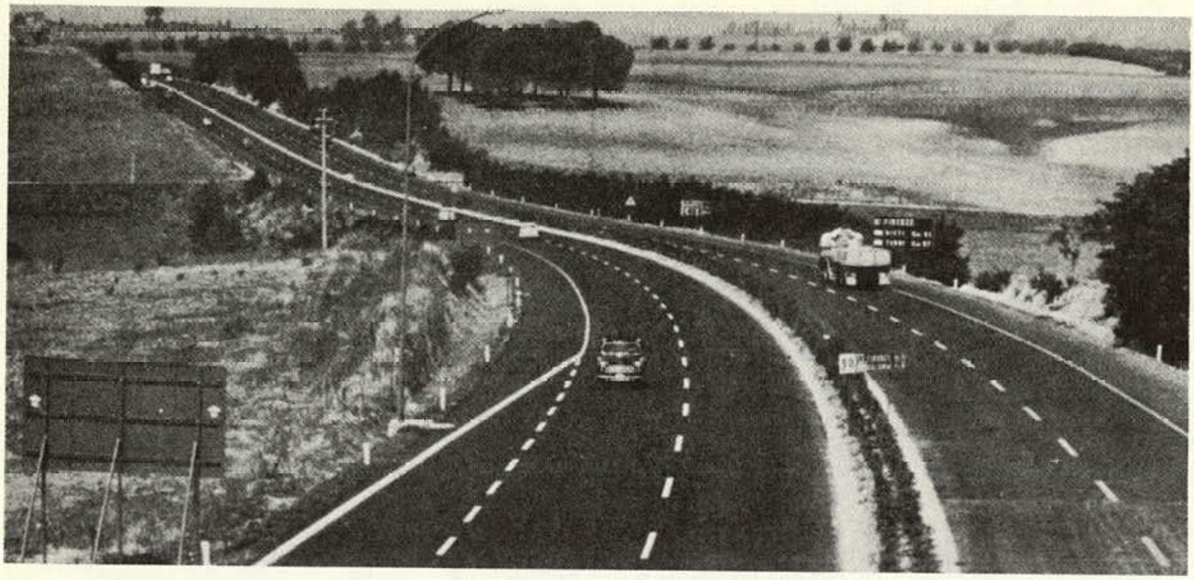

Figure D-2. Pavement markings, Italy. Source: *Traffic Engineering and Control*, Apr. 1968, p. 620.

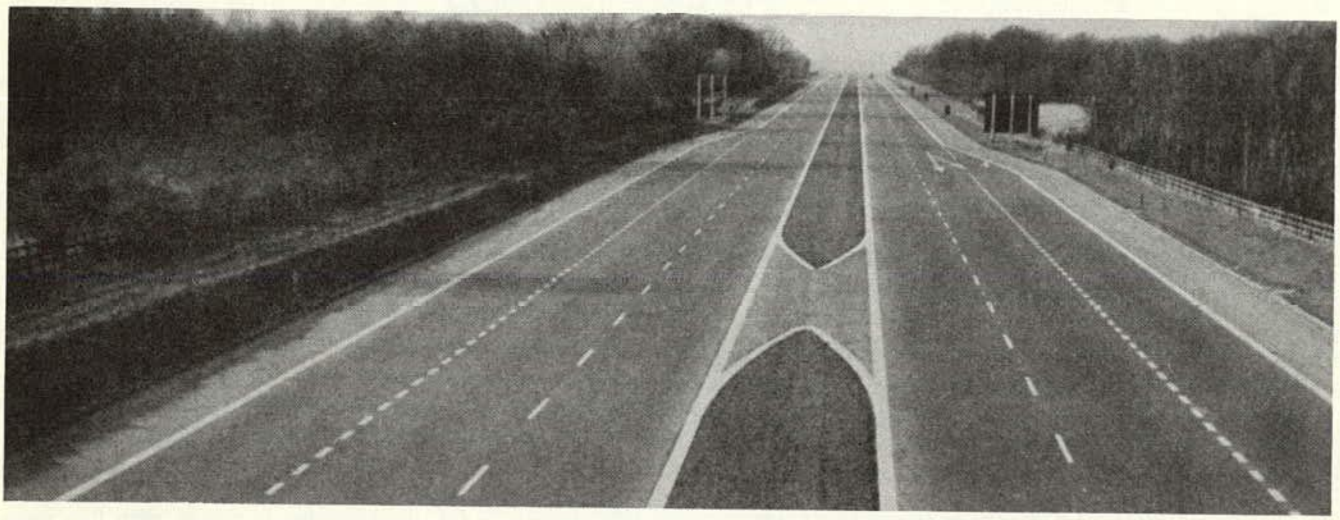

Figure D-3. Pavement markings, England. Source: *Traffic Engineering and Control*, Sept. 1966, p. 263.

such as channelizing signs at the beginning of deceleration lanes (Canada), turn-off signs at the gores (most countries), delineators (Canada, Japan), and arrow markings at deceleration lanes (England, Japan when sight distances are restricted) are frequently used.

Stop Approaches

Generally, a delineation system comprised of several treatment elements is required at a stop approach. The systems used in Canada, England, and Italy are as follows:

Canada:

1. Approaches to intersections:
   (a) Center lines. Double solid white lines or combination of solid and broken white lines (i.e., no-passing zone lines) on rural signalized intersections. Single solid white line on rural unsignalized intersection (no special treatment for major highway). Single solid white line on urban intersection. The dimension of the line is the same as the corresponding no-passing zone lines in each situation.
   (b) Edge lines. No edge line is provided.
2. Stop lines:
   (a) Solid white lines no less than 12 in. nor more than 24 in. in width.
   (b) This line shall extend from the right curb or pavement edge to the directional dividing line.

Figure D-4. Pavement markings (ramps), Japan.

(c) Where a crosswalk is located at a control point, the separation between the crosswalk line and the stop line shall be 3 ft.

3. Supplemental treatment: STOP signs at unsignalized intersections.

England:

1. Approaches to intersections:
   (a) The warning lines are used for both center lines and lane lines in the case of stop approaches. The patterns are the same as those for either the urban- or rural-type warning lines. That is, urban, 40 mph or less, 18-ft module (12-ft mark, 6-ft gap); rural, over 40 mph, 27-ft module (18-ft mark, 9-ft gap).
   (b) Center line. Warning line 6 in. in width for signal-controlled junctions on four-/or six-lane carriageways. Warning line 4 in. in width for other signal-controlled junctions.
   (c) Lane line. Warning line 4 in. in width for signal-controlled junctions.
   (d) Edge line. No edge lines are provided.

2. Stop lines: Commonly located 3 ft. in front of the nearside primary sign. Normally at right angles to the center line of the carriageway, even at skew junctions. Single stop line (8 in. urban, 12 in. rural) (solid white) when controlled by traffic signal or police. Double stop line (solid white) when controlled by STOP signs (each 8 in. wide, spaced 12 in. apart, with STOP signs and worded STOP markings). Give-way lines are two broken white lines (2-ft mark, 1-ft gap), 8 in. wide and spaced 12 in. apart for minor roads at intersection with major roads.

3. Supplemental treatments: Lane indication arrows (12-ft length for ≤ 40 mph, 18-ft for >40 mph). Lane destination marking at heavily traveled junctions.

Figure D-5. Pavement markings, Japan.

Italy:

1. Approaches to intersections:
   - (a) Center lines. Combination of solid white and broken white line (both 4¾ in. wide, spaced 4¾ in. apart) for intersections with broken center line on approach. Double white solid line (4¾ in. wide, same spacing) for intersections where approach roadway is divided by solid line.
   - (b) Lane lines. Either broken white line or solid white line.
   - (c) Edge line. Solid yellow line.

2. Stop lines: Used either at unsignalized minor roads or signalized intersections.

3. Supplemental treatments: STOP sign, STOP marking.

Synthesis of Marking Practices, by Country

Canada

Five types of line are used as center lines in Canada; i.e. solid, broken, double solid, double broken, combination of solid and broken line (all are white).

All lines are approximately the same width (4.5 to 5.5 in.).

Figure D-6. Pavement markings, Germany.
Source: *Traffic Engineering and Control,* Apr. 1968, p. 615.

Edge lines are used only at dangerous or complex situations (such as narrowed bridge sections, sharp curve sections, acceleration lanes, deceleration lanes). Yellow is used for the edge line (see Fig. D-1).

Double solid lines are used for center lines when there are more than two lanes. On two-way, two-lane roads, double solid lines are used to indicate no passing zones.

England

One of the most noticeable features of marking practices in England is the detailed use of broken lines. England uses a single-color system that makes it necessary to use many types of broken lines to meet the several traffic situations. Broken lines are used for three primary purposes—warning markings (used in dangerous situations, but not so serious as to require a double solid line, which is used for no-passing zones); lane markings; and center markings. (See Fig. D-8 for details.)

Another noticeable difference in marking practices in England, as opposed to other European countries, is the widespread use of reflecting road units to complement the pavement markings. (Road studs are generally used as supplements to marking lines; rarely are they used alone.)

England lags behind other European countries in the use of edge lines. Twelve-inch-wide edge lines are provided on the motorways, but only rarely on other roadways. (See Fig. D-9; also, note lane line and speed change lane line.)

The "warning" line is used extensively. This broken line consists of longer marks and shorter gaps than the standard line and is used to designate a degree of restriction between the normal lines and no-passing zones. These warning lines are installed at crests and sharp curves where the sight distance is greater than the "prohibitory" criteria (criteria to provide no-passing zone lines), but less than the "warning" criteria.

	SIGHT DISTANCE (FT)	
SPEED (MPH)	PROHIBITORY	WARNING
30	200	300
40	300	425
50	425	650
60	650	950

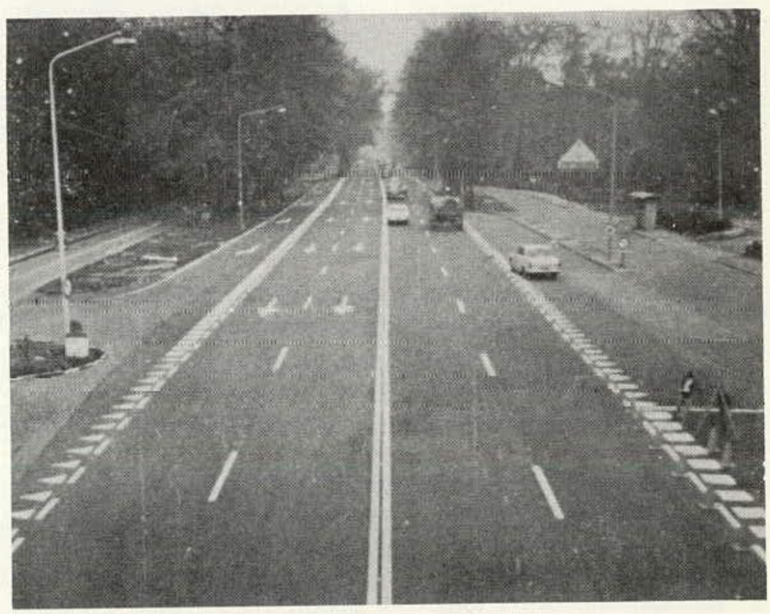

Figure D-7. Pavement markings, The Netherlands.
Source: *Traffic Engineering and Control,* Apr. 1968, p. 618.

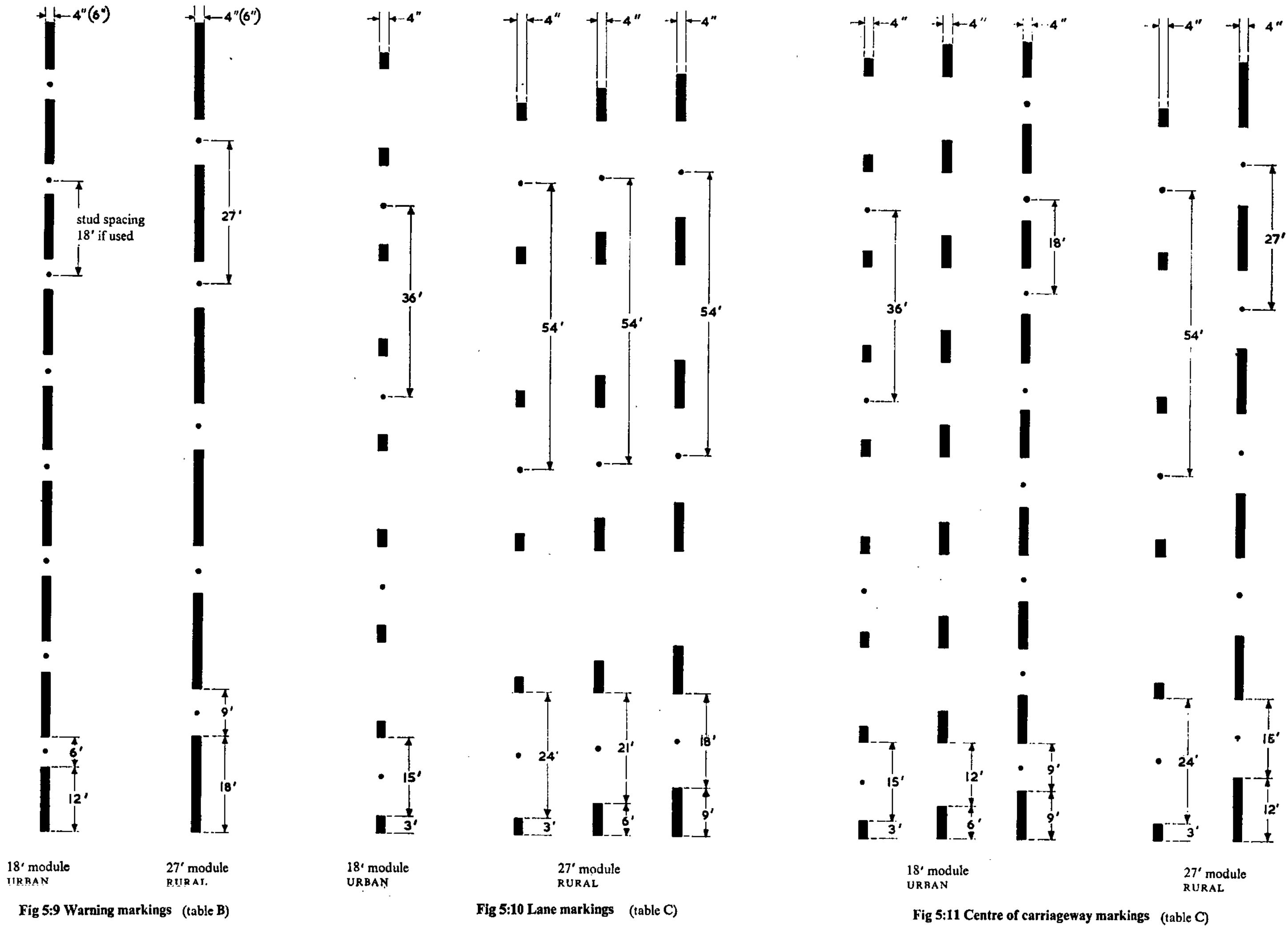

Figure D-8. Broken-line patterns, England.

Warning lines are also used where it is necessary to warn drivers of the presence of a road junction and to mark the approach to obstructions.

Two modules are used for all broken lines (center lines, lane lines, warning lines), as indicated in Figure D-8.

The Netherlands

Wide, rectangular markings are used in The Netherlands to delineate the edge of the roadway. (See Fig. D-10; also, note brick-paved shoulder.)

Italy

Either continuous or broken yellow lines are used for edge lines in Italy, depending on whether they can or cannot be crossed in normal driving conditions (see Fig. D-2). As a general rule, the edge lines are approximately 5 in. in width; when broken lines are used the dimensions are 3.3-ft marks with 3.3-ft gaps. On motorways, and some urban roads, 12-in.-wide edge lines are used. The edge lines are always reflectorized.

All road markings are white except edge lines, waiting restrictions, and bus stops, all of which are yellow. (Lines indicating attended parking areas are blue.)

The marking system in Italy is similar to that in Canada.

Japan

Solid yellow lines are used for no-passing zones in Japan.

Normal widths of lane lines and center lines are 4 in. for rural and urban highways and 6 in. for expressways. Edge lines are generally wider than the center or lane lines—normal widths are 6 in. for general highways and 8 in. for expressways (see Fig. D-4). The use of wider lines for expressways is a recent development. The effect of widening the edge lines has not been investigated yet.

Wide median stripes (30 in.) are used in Japan (see Fig. D-4).

Broad delineation lines are used for speed change lines. These are 18-in.-wide broken lines with 10-ft marks and 10-ft gaps.

The pattern of broken lane lines was recently changed

Figure D-9. Edge line marking, England. Source: *Traffic Engineering and Control*, Apr. 1968, p. 614.

from 1:1 (30-ft mark, 30-ft gap) to 2:3 (26⅔-ft mark, 40-ft gap) on expressways on the basis of visual presentation. (Compare Figs. D-5 and D-4.)

France

The two-color system for marking in France is different from that of the other countries surveyed. France uses white for edge lines and yellow for all other delineation purposes.

Germany

Maneuvering sections (motorway entrance and exit ways, as well as acceleration and deceleration lanes) are always separated from the main roadway by a broad broken line (50 to 75 cm wide) (see Fig. D-6).

Germany uses a "safety" line, similar to the "warning" line in England. This type of line is used when crossing the center line is dangerous but unavoidable for certain vehicles because of the geometric characteristics of the road (e.g., on right corners, narrow roadways). In these cases, a broken line with a 5-ft mark and 5-ft gap is used. It is reported that these "safety" markings give an optical impression of an almost unbroken line, and that drivers tend to stay on their side of the line.

One of the most noticeable differences in marking practices between Germany and the U.S. is the treatment of pavement edges. In Germany, broad side strips (no pavement edge markings, but strips between the roadway and shoulder paved in contrasting material to delineate the edge and also provide side clearance for safety) are used frequently. For example, white side strips of portland cement concrete (30 in. wide) are placed at both edges of dark asphaltic roadway pavements. (Recently, there is a tendency to use paint or plastic marking materials in place of the portland cement concrete.)

If the edge lines are to be reflectorized, the *ballotini* (glass beads) are applied only over a width of 12 to 15 cm from the inner edge of the line. As an alternative, 12- to 15-cm-wide lines are painted on the pavement in addition to the contrasting treatment; these lines are then reflectorized.

Note: Side strips of the same width paved with a white pebble treatment are used in Austria; side strips of the same width, and sometimes wider, are paved in brick in The Netherlands. In other European countries, where the side strips are not used, broad edge markings are frequently provided. In England and Italy, 12-in. edge lines are used on some motorways. Various widths of side strips are used, as follows:

30 in.—Germany, Japan (on rural freeways).
20 in.—Germany, Japan (on urban expressways), Denmark, Sweden, The Netherlands.
16 in.—Belgium.
12 in.—England.
8 in.—France.

More and more European countries are using broad paint markings in place of contrasting materials as edge delineation.

Pavement Marking Materials

The principal pavement marking materials used are paints, thermoplastics, adhesive sheet materials, inset mastic asphalt, etc.—with paints and thermoplastics being the most common by far.

Figure D-10. Edge marking, The Netherlands.

Paints

Canada. Paint is the most common method for applying pavement, curb, and object markings. Constant improvement in paints, equipment, and methods of application has resulted in wide use for pavement markings.

England. Relatively less emphasis is placed on paints—the English manual mentions that paint is particularly useful for temporary markings and for situations where the markings are subject to little traffic wear because of the limited durability.

(The relative initial costs of surface-dressed lines, reflectorized lines, and reflectorized thermoplastic lines are approximately in the ratio 1:2:3 in England—considerably different from the ratios in the U.S., where thermoplastic lines cost approximately 15 times as much as paint lines. Because the estimated life of the reflectorized thermoplastic lines is three to four times that of the reflectorized paint lines, the annual cost for thermoplastic is considerably less than that for paint in England. Hence, England depends largely on thermoplastics and "catseyes" for permanent markings.)

Germany. Only white marking paint is used. The current specifications require the marking paint to be applied at a thickness of 0.4 mm.

Japan. The criteria for the use of paint are as follows:

1. Normal paint:
   (a) Paints are used for both horizontal and vertical surfaces.
   (b) They are suitable for center lines that are not subject to heavy traffic, or edge lines.
   (c) It is possible to mark worded or symbol markings with paint, but it is considered less efficient than thermoplastics.
2. Thermosetting paints:
   (a) Thermosetting paints are used for longitudinal lines only.
   (b) They are particularly suitable for center lines, lane lines, or pavement edge lines of expressways.

The Netherlands. The paint and beads are mixed in proper proportions just before application. A wet-film thickness of between 0.4 and 0.5 mm is specified.

Sweden. Alkyd paint with glass beads is used for markings in open country. The refractive index of the glass bead is about 1.5, the application rate being 0.7 to 0.8 kg per liter of paint.

Thermoplastics

There is definitely a trend in Europe toward the use of more thermoplastic marking materials, with subsequent deemphasis on ordinary paint. The relative costs of thermoplastic marking materials and paint are considerably different in Europe from what they are in the U.S., the initial costs being much closer in Europe.

England. Two general types are used—superimposed thermoplastic material and inset thermoplastic material. Superimposed thermoplastic material is applied hot and sets on laying; it has good durability and is appropriate for use in all but the most heavily traveled urban areas. Inset thermoplastic material is more finely graded than the superimposed type; it is generally used at urban sites because of its greater durability.

Germany. The use of cold and hot plastics incorporating glass beads has been permissible since 1960. These plastic compounds are superimposed on the roadway only after thorough cleaning, and the application of a preliminary coating for certain plastic compounds. On urban roads the plastic markings are often inset into the road surface.

Italy. Superimposed and inset thermoplastic materials are used for road markings.

Japan. The following criteria have been developed for the use of thermoplastics:

1. Thermoplastics are appropriate for center lines, pavement edge lines, channelizing, etc.
2. A thickness of 1.5 to 2.0 mm is desirable for pedestrian crosswalks and stop lines being subjected to heavy wear, and markings at curved sections and intersections.
3. The inclusion of glass beads is not necessary for the broad markings at lighted sections (e.g., the broad broken lines between speed change lanes and through lanes on lighted expressways); light bead applications are used at pedestrian crosswalks.

The Netherlands. Thermoplastics are used primarily on main highways with high traffic densities. The material is applied to the road surface in a 3-mm-thick layer.

Sweden. Thermoplastics are used in urban areas, especially for pedestrian crossings, but also for lane lines.

It is reported that certain problems are encountered if the plastic materials are applied at a thickness greater than 3 mm (⅛ in.). There is a noticeable effect on directional stability when light vehicles pass over the heavier markings. In addition, water tends to accumulate on the higher side of the markings; depending on the superelevation of the road, this water accumulation may extend 6 to 8 in. and give rise to disagreeable reflections. In general, it is desirable to hold the thickness to about 1.5 mm or less.

Prefabricated Sheet Materials

Prefabricated sheet material is not popularly used at this time, but England and Japan have experimented with it, and have drawn conflicting conclusions.

England reports that this material provides satisfactory skid resistance, has good durability, is of uniform thickness, and does not spread in hot weather under the weight of heavy traffic.

On the other hand, Japan reports that the sheet material is poor in reflectorization (glass bead bonding problems) and skid resistance. Therefore, their manual states that the material should not be used for primary markings, such as center lines, lane lines, and edge lines. Advantages are easy application and high wear resistance; therefore, it could become an effective marking material if the faults mentioned can be resolved.

Reflectorization

General considerations in reflectorization are:

1. Improved night visibility is obtained by the use of minute glass beads (called *ballotini* in Europe).
2. The glass-beaded surface returns a greatly increased portion of the incident light in the direction of its source and causes the markings to appear luminous at night under normal headlighting.
3. On the other hand, the beads have little or no effect in the daytime and even look slightly dark and slippery if the bead application is high.
4. Most of the reflectivity effect is lost when the lines are wet, especially if rainfall has been sufficient to build up water films.
5. There are two methods of applying the glass beads —pre-mixed and the drop-on method. Pre-mixed paint is generally used in all the countries surveyed except Germany.

All the countries surveyed recognized the desirability of reflectorization on unlighted roads. There is some controversy regarding reflectorization in illuminated areas. Examples of criteria in specific countries are:

1. Canada: All pavement markings should be reflectorized in rural areas—directional dividing lines, lane lines, no-passing zone lines, pavement edge lines, pavement width transitions, approaches to railway crossings, etc. Reflectorization should be used in urban areas, except in well-lighted sections.
2. England: No-passing zone lines should always be reflectorized (reflecting road studs are provided between the two lines, also). Warning lines, lane lines, edge lines, stop lines, and give-way lines should be reflectorized on unlighted or heavily traveled sections and in areas subject to fog.
3. Italy: Edge markings should be reflectorized. Pavement markings in urban areas are generally not reflectorized.
4. Germany: The glass beads (diameter 0.1 to 0.5 mm) are generally sprinkled on after applying the paint. (Most other European countries use pre-mixed marking materials. However, Italy does use drop-on glass beads for some markings not subject to heavy vehicle wear.)

POST DELINEATORS

Post delineators are effective aids for nighttime driving. They are considered to be guide markings rather than warning devices and should never be substituted for a proper warning sign. The purpose of delineators is to outline the edge of the roadway and to indicate the roadway alignment. Post delineators usually consist of reflector units (glass, plastic, or reflective sheets) mounted on suitable supports.

In England, post delineators are not normally used on all-purpose roads except to mark hazards or obstructions near the edge of the carriageway. On motorways, however, small marker posts, 30 in. high, carrying beaded reflective strips showing red on the nearside and white on the offside, are located on the outer edge and on the median at 330-ft intervals.

The warrants for post delineators in Japan are similar to those in the United States. The only differences are that the maximum spacing is shorter and the application of delineators at speed change lanes is somewhat complicated.

The use of delineators in Austria, Germany, and New Zealand is somewhat different from other countries. They use delineators for both nighttime and daytime. Post delineators in these countries function both as guide posts and delineators.

Color Coding

Similar to pavement markings, there are two color categories—single-color system countries and two-color system countries. White is used in single-color system countries for dangerous situations only, whereas in two-color system countries white is used for normal situations and color (yellow, red, etc.) is used for dangerous or special situations.

1. Single-color system countries: Israel and Sweden use white reflective elements for dangerous situations (e.g., sharp curves).
2. Two-color system countries: Canada, Finland, Germany, and New Zealand use white for normal sections (tangents, flat curves, flat gradients) and yellow for dangerous situations (sharp curves, rolling sections, merging and diverging areas). Japan uses white for through roadway and orange for interchange areas (e.g., speed change lanes, ramps). France uses white for the left side of curves and red for the right side of curves.

Delineator Materials and Design

Post delineators are composed of reflector units and suitable supports to mount the reflectors. Most countries use either prismatic reflectors or reflective sheets for the reflector unit. Reflective sheets are often used for all reflective purposes because of their simplicity of application; but their reflective efficiency is inferior to that of prismatic reflectors, as shown by Table D-3 (taken from a Japanese manual).

Reflective units must be capable of reflecting light clearly visible, under normal atmospheric conditions, from a distance of 1,000 ft in order to delineate the roadway alignment. Reflective sheets are usually not efficient enough to meet this purpose.

Concerning the reflectivity of reflectors, Canada (U.S., also) specifies visibility from a distance of 1,000 ft under clear atmospheric conditions when illuminated by the upper beam of standard automobile headlamps.

Delineator characteristics (materials, height from the pavement surface to the center of reflectors, and dimension of reflectors) in the countries surveyed are given in Table D-4. Several of these delineators are shown in Figure D-11. In Germany, as well as in some other foreign countries, flexible posts are commonly used.

TABLE D-3

REFLECTIVE EFFICIENCY OF POST DELINEATORS

		REFLECTIVE DIST. (FT) FOR LIGHT ANGLE OF		
MATERIAL	COLOR	0°	10°	20°
Prismatic reflector	White	1600	1540	1100
	Yellow	990	770	500
	Red	320	250	100
Reflective sheet	White	270	270	220
	Yellow	130	120	110
	Red	70	60	40

Lateral Placement and Spacing

Table D-4 gives the lateral placement and spacing of post delineators for various countries. As indicated, the usual lateral placement is from 10 to 20 in. (25 to 50 cm) from the outer edge of the shoulder.

Maximum delineator spacings for tangent or flat curve sections range from 167 to 330 ft. In considering the maximum spacing of delineators, the countries can be divided into three groups, as follows:

Maximum spacing 330 ft—England, New Zealand.

Maximum spacing 200 ft—Canada, Israel.

Maximum spacing 167 ft (50 m)—Finland, Germany, Japan.

Canada, Israel, and Japan require that five delineators be visible at all times on curved sections. New Zealand requires only three.

RAISED PAVEMENT MARKERS

From the worldwide point of view, raised pavement markers are used only as a supplement to standard pavement markings. Those countries that use raised markers always include them in the category of road markings.

Many countries do not use raised markers. Canada provides no specifications in their manual. Finland answers that some experimentation is planned, but there are no raised markers in use. France claims that they are "dangerous." Sweden gave no indication of their use.

On the other hand, England uses road studs extensively. The spacing of road studs varies from 18 to 54 ft, according to the situation. Except for pedestrian crossings and parking bays (in this case the spacings are shorter), road studs are always used in conjunction with road markings.

Germany and Japan use road studs for both longitudinal and transverse lines; but the use of road studs for longitudinal lines is rare in normal sections—they are usually

TABLE D-4

DELINEATOR CHARACTERISTICS AND PLACEMENT, OTHER COUNTRIES

				PLACEMENT	
COUNTRY	MATERIALS	HEIGHT TO CENTER	DIMENSION	LATERAL	MAX. LONG.
Canada	Sheets	48 in.	4×8 in. (rect.)	2 ft clear of shoulder, but in no case more than 12 ft or less than 4 ft from edge of pavement	200 ft [b]
England	Sheets	30 in.	Strip	—	330 ft
Finland	—	75–100 cm (30–40 in.)	75×200 mm. (3×8 in.)	0.30 to 0.50 m from edge of shoulder	50 m (167 ft)
France	—	No std.	—	0 to 3 m, usually 0.25 to 0.50 m, from edge of shoulder	—
Germany	Any refl.	75 cm (30 in.)	4×18 cm. (rt.) 2 at 0.6 cm. (lt.)	50 cm from edge of shoulder	50 m (167 ft)
Israel	—	24 in.	—	At edge of shoulder	200 ft [b]
Japan	Plastics, glass	120 cm (48 in.)	7 cm (3 in.)	50 cm from shoulder on expressways; 10 to 25 cm from edge of shoulder on other roads	50 m [b] (167 ft)
New Zealand	Sheets [a]	33 in. 27 in.	Single white 5×3 in. Dbl. yellow 5×1½ in. each	At least 4 ft of lateral clearance where no shoulder exists; not farther than 10 ft from edge of traffic lane	330 ft [c]
Sweden	—	100 cm (40 in.)	Various; 5 to 20 cm	0 to 2 m from edge of shoulder	—

[a] Scotchlite. [b] Requires 5 delineators visible at all times on curved sections. [c] Requires 3 delineators visible at all times on curved sections.

used only in foggy or mountainous areas. However, the use of studs for transverse lines (stop line, pedestrian crosswalk) is common.

Raised Marker Practices

England

England provides the most detailed information on the use of raised markers. No other country uses raised pavement markers as widely as England, where two types of raised markers are specified, as follows:

1. Non-reflecting road studs. These are widely used for marking the limits of pedestrian crossings and their approaches (circular or square studs) and of parking bays (triangular studs). The studs may be of stainless steel or various forms of plastic.

2. Reflective road studs. All reflecting road studs must be of a type approved by the Minister of Transport. They may be either reflex lens type, or solid, with beads. The commonly used reflex lens type (Catseye) consists of a rubber insert carrying two reflex lenses set into a cast-steel base. Passage of a vehicle wheel over the stud depresses the rubber insert, which is designed to wipe the surface of the lenses by a "squeegee" action. The studs may be unidirectional or bidirectional, and the lenses may be colored white, red, or green according to the requirements (see Fig. D-12).

Solid reflecting studs may be either circular or rectangular in shape. If the former, they are usually dome-shaped; if the latter, wedge-shaped. They are fabricated in a hardened resin with *ballotini* (minute glass beads) dispersed throughout the material. The studs are affixed to the road surface by means of a suitable adhesive.

Another type of a solid reflecting stud employs the principle of corner cube reflecting. The stud is fabricated in plastic material, is wedge shaped, and, subject to the outcome of present trials, may be suitable for carriageway markings.

The common practices for raised markers in England are as follows:

1. Use of studs for longitudinal lines. Studs are always to be used as a supplement to the conventional pavement markings.

(a) Prohibitory marking (double lines of paint marking).

Prohibitory—12-ft stud spacing (in the middle of double solid paint marking).

Permissive; broken—12-ft stud spacing (one line is broken, with 3-ft mark, 15-ft gap; other is solid).

(b) Warning marking (single broken line of paint marking).

Urban (18-ft module)—18-ft stud spacing (12-ft mark; 6-ft gap).

Rural (27-ft module)—27-ft stud spacing (18-ft mark; 9-ft gap).

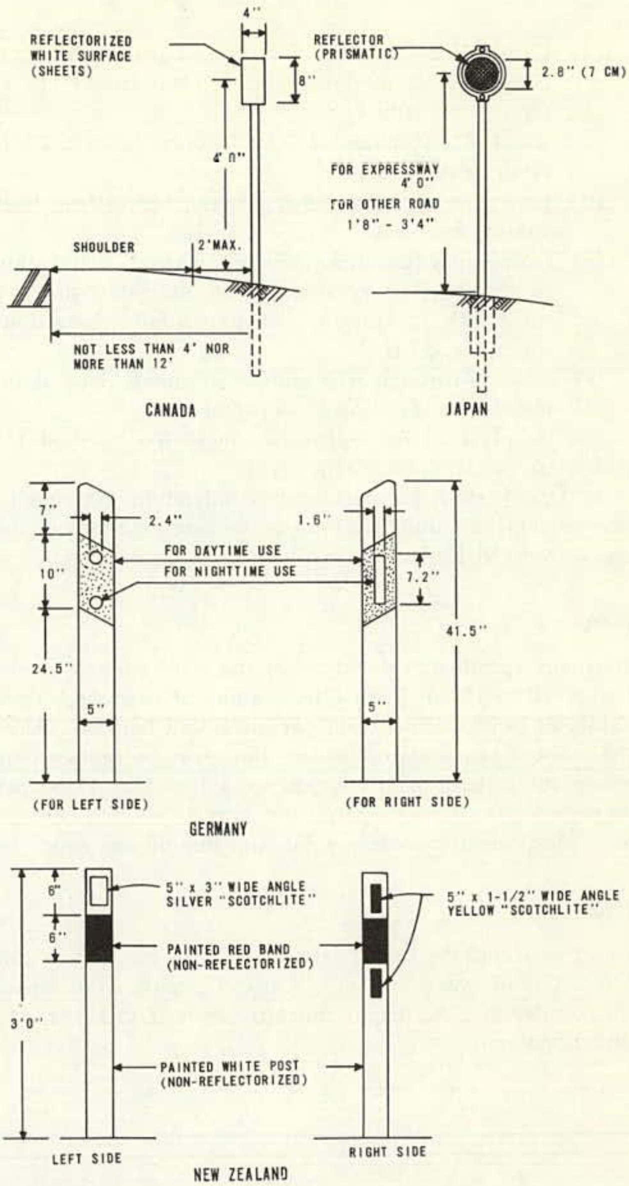

Figure D-11. Post delineators, other countries.

Figure D-12. English "Catseye" pavement marker.

(c) Center line (single broken line of paint marking). Urban (18-ft module)—36 ft (two lanes); 18 ft (four or six lanes).
Rural (27-ft module)—54 ft (two lanes); 27 ft (four or six lanes).
(d) Lane line. If used, 36-ft spacing for urban, 54-ft spacing for rural.
(e) Pavement edge lines. Where required, delineation of the edge in rural areas on unlighted primary route, 54 ft (max.). At particularly hazardous situations, 27 ft.
(f) Between through lane and speed change lane at intersections. Spacing of 54 ft (max.).

2. Use of studs for transverse lines. To be used for pedestrian crossings (non-reflective).

3. Use of studs for parking bay indication. Triangular non-reflectorized studs are used to indicate the limits of the space reserved for vehicle parking.

Germany

Germany specifies that instead of the solid painted center line of 10 to 15 cm (4 to 6 in.), a line of road studs consisting of at least three studs per meter can be used. Also, the marked segments of broken lines can be replaced by groups of at least six roadstuds spaced at least three per meter. A line of studs spaced not over 25 cm can be used as a substitute for a white solid stop line 50 cm wide.

Israel

Israel indicated the use of raised pavement markers as follows: Use of raised markers, "Catseye"; color, white; spacing, similar to U.S.; height above roadway, 1 in.; type, one directional only.

Japan

Japan specifies that the road studs should be used in principle as an aid to pavement paint markings (including thermoplastic, and adhesive sheets) for the following lines, if required: (a) center lines, (b) pedestrian crossing (only when unlighted road), (c) pavement edge lines, and (d) center point of intersection.

It is specified that when the pavement paint marking is not appropriate for low-skid-resistance pavements, the road studs can be used instead.

The manner in which road studs are used for center lines, edge lines, and pedestrian crossings is as follows:

1. For center lines (white reflectors):
   (a) Used as a supplement to paint markings. Broken lines—at both ends of dashes. Double lines—between lines at 10- to 20-ft spacing.
   (b) Used alone. Spaced at 10 to 20 ft.
2. For pavement edge lines. When used to assist pavement edge lines, road studs should be installed along the inner side of the edge line. Spacing between 10 and 20 ft. Orange when installed on outside of curves; white in all other cases.
3. For pedestrian crossings. Installed along both edges of painted crosswalks at spacing between 16 and 24 in.

New Zealand

New Zealand reported that they were in the process of installing trial sections using linear groups of raised pavement markers to substitute for dashed lane lines. They are using groups of one reflective Stimsonite marker followed by four small, domed, white, non-reflective ceramic markers.

APPENDIX E

BENEFIT-COST ANALYSIS *

"Benefit-cost," "cost-benefit," and "cost-effectiveness" are three expressions used to refer to essentially the same kind of analysis. Authors tend to have personal preferences for one or another of these terms and consistently use their choice. In analyses of military problems, the term usually used is cost-effectiveness.

Sometimes the term "systems analysis" is used to refer to benefit-cost analysis, but many authors make a distinction here. For example, Quade (*339*) says: ". . . to qualify as a Systems Analysis a study must look at the entire problem and look at it as a whole." He says that cost-effectiveness is just one stage in systems analysis. Bell (*304*), on the other hand, considers the difference as a matter of emphasis. He maintains that "If the emphasis is on finding significant differences in the costs or resource requirements among the available alternatives for carrying out some specific task, the analysis is generally referred to as a cost-effectiveness analysis. The systems analyst, on the other hand, is likely to be forced to deal with problems in which the difficulty is deciding what ought to be done, not simply how to do it. Systems analysis, thus, puts greater

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emphasis on the suitability of the task and the augmentation of alternatives."

Sometimes a cost-effectiveness study is referred to as "operations research"; and there are a few authors who, like Fisher (*300*), reject all such expressions and call what they are doing "cost-utility" analysis.

The subject of this survey was not limited to any narrow definition of benefit-cost and thus includes much of what Quade would call systems analysis or what Fisher would refer to as cost-utility analysis.

This appendix is divided into two sections. The first is concerned with the general methodology of benefit-cost analysis; the second, with the evaluation and quantification of benefits of highway projects.

I. THE METHODOLOGY OF BENEFIT-COST ANALYSIS

The first question is: What is benefit-cost analysis? Prest and Turvey (*301*) state that benefit-cost analysis is ". . . a practical way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the further, as well as the 'nearer,' future) and a wide view (in the sense of allowing for side effects of many kinds on many persons, industries, regions, etc.); i.e., it implies the enumeration and evaluation of all the relevant costs and benefits." Quade (*340*) says: ". . . it is any analytic study designed to assist a decision-maker identify a preferred choice from among possible alternatives." In a sense, it is a way to look at a problem, analyze it, and arrive at some type of solution. It involves the comparison of various alternatives to achieve a specific objective and essentially consists of the following six steps:

1. The statement of the desired objectives.
2. A complete specification of all the relevant alternatives.
3. An estimation of all the costs involved.
4. An enumeration of all the benefits.
5. Development of a model, either verbally or mathematically.
6. Development of criteria for choice among the relevant alternatives.

It must be cautioned that these steps are so interrelated that any attempt to discuss them as mutually exclusive parts is surely doomed to failure. This appendix, then, examines each of the steps while keeping in mind their mutual interdependence.

OBJECTIVES OF PROPOSED INVESTMENTS

Any benefit-cost analysis must start with an enumeration of the objectives that the projects or programs are designed to attain. There may be one objective or many. What is important is that the objectives be enumerated clearly and completely. There is no room for ambiguity. The objective function cannot be misspecified. The importance of the objective function is taken up elsewhere in this appendix. At present, it should suffice to say that the objective function need not be formulated mathematically. It may be either verbally or mathematically explained, or both. What is necessary is that it be clear.

Alternatives

All the alternative systems or programs that, in the eyes of the analyst, may possibly attain the stated objectives should be enumerated exactly and in great detail. Sometimes all the alternatives are not obvious. In an example taken from the military, Quade (*340*) asserts that: "They need not be obvious substitutes for one another or perform the same specific function. Thus, to protect civilians against air attack, shelters, 'shooting' defenses, counterforce attack, and retaliatory striking power are all alternatives." The analyst must explore all avenues to obtain a list of all the alternatives.

Another important aspect concerning the specification of the alternatives is that if all the initially listed alternatives are examined, and no one of them achieves the desired objectives adequately, the analyst may be forced to design new alternatives. As McNamara (*300*) has stated: "Not only is it important to systematically examine all of the relevant alternatives that can be identified initially, but also *to design additional ones* if those examined are found wanting." This is one of the primary advantages of benefit-cost analysis: to force the examination and exploration of new avenues where alternatives may lie.

Grant (*362*) points out the need for the analyst to examine all of the relevant alternatives. If this is not done, a proposed alternative may seem attractive when in fact it is not the "best." He provides an example of two proposed highway improvements. He says: "Proposal A required a major improvement of an existing through highway. Proposal B called for an entirely new location that would relegate the existing road chiefly to the service of local traffic. A prospective favorable consequence of the new location was to make possible the development of new economic activity in a certain area not now served by an adequate highway. This consequence, included in the economic analysis as a 'benefit' for B but not for A, was a major factor in the analyst's recommendation favorable to Proposal B. The analyst failed to recognize that the same benefit could be obtained by making a relatively small additional investment to add to Proposal A a low-cost secondary road that would serve the new area."

COSTS

A good benefit-cost study requires the complete enumeration of all the relevant costs of each alternative project. Even if all the costs are known and can be quantified, this is still not an easy task. The costs internal to the project must be broken down by type. One such method mentioned in the literature is to break them down into three categories—fixed or sunk costs, investment or capital, and maintenance costs. Sunk cost is money that has already been expended on plant and equipment or resources. These are costs that have been made in the past. McCullough (*330*) and other authors maintain that because these costs were expended in the past they have no relevance to future systems. In other words, they should not be counted as a cost of the various systems that the analyst is examining. Grant (*362*) explains that only the differences among alternatives is what is relevant in their comparison. Inasmuch as sunk cost is the same for all alternatives, there is no need to consider it in an analysis. He states that ". . . everything that has happened up to the moment of decision between alternatives is common to the alternatives and therefore is irrelevant in the choice. In general, past investments should be viewed as irrelevant in present decisions except as they may affect the future differently with different alternatives for the future." Investment or capital costs are those costs that are outlays on plant and equipment for each alternative system. Maintenance costs are those costs that accrue over time and are expended to keep the various facilities at a suitable level of performance. These three categories, of course, can be broken down into various subcategories to enumerate more explicitly and completely the costs involved.

One such method to break down, enumerate, and calculate the various costs of a project is presented by Widerkehr (*373*) in his discussion of the net average annual cost of a highway improvement project. This cost is ". . . the amount by which the annual cost of the improvement exceeds the cost of the unimproved location." He says that costs can occur for:

1. Obtaining the right-of-way.
2. Grading, drainage, and minor structures.
3. Major structures.
4. Pavement and appurtenances.

He then presents the following equation to calculate the net average annual highway improvement project cost:

$$\Delta H = (C_1K_1 + C_2K_2 + C_3K_3 + C_4K_4) + \Delta M \quad \text{(E-1)}$$

in which

ΔH = net average annual highway improvement project cost;
C_1 = capital cost of right-of-way;
C_2 = capital cost of grading, drainage, and minor structures;
C_3 = capital cost of major structures;
C_4 = capital cost of pavement and appurtenances;
ΔM = change in annual maintenance and operation cost for the project; and
K_1, K_2, K_3, K_4 = capital recovery factor for the known interest rate and service life of the respective item.

If the service life of an improvement is T years and the known interest rate is r, the capital recovery factor is given by:

$$K = \frac{r(1+r)^T}{(1+r)^T - 1} \quad \text{(E-2)}$$

Widerkehr states that "the capital recovery factor in effect distributes the capital costs over the T years of service equally, taking into account the time value of money."

The use of capital recovery factor is typical of the analyses in the highway field. The rationale behind its use is that the highway agency must finance its improvements with borrowed money or that, even if the highway agency does not borrow money, the inclusion of interest is an indication of the investment opportunities foregone by the taxpayers when the highway agency spends tax money.

Another problem in cost estimation is the estimation of the planning or analysis period. Widerkehr assumes in his model that the service life of the improvements is known. This is usually not the case in most benefit-cost studies. The estimation of the project life or planning period is usually a highly subjective process. It depends on personal judgments not only of the physical length of life of the project, but also of the likelihood of any changes that may make a particular project obsolete. The estimation of the planning period is further complicated in the analysis of highway improvement projects due to varying physical length of life for each component of the improvement and because of the extreme uncertainty involved in the estimation of traffic growth in the more distant future. The estimation of traffic growth is an important part of an analysis of highway improvement, because the amount of benefit accruing from a given improvement is directly related to this factor. If the planning period is too long, the analyst may not be able to estimate this critical factor accurately. This can result in the wrong alternative being considered "best" or an unacceptable project being accepted.

There is not much agreement in the highway field as to what constitutes the maximum length of time to use as the planning period. Periods of from 10 to 100 years have been mentioned by various authors as the maximum planning period. Some authors maintain, though, that the planning period should be either the physical length of life of the project or the useful life of the project, whichever is shorter.

Niskanen (*336*), however, takes a different view of the estimation of the planning period. He says that:

1. "The first year of the planning period should be the first year that the expenditures for a specific system might be influenced by the analysis," and
2. "The last year of the planning period is arbitrary if the value of all assets at that time can be estimated accurately."

He then maintains that the next task of the analyst should be to estimate the value of all the assets at the beginning and at the end of the planning period. He states: "All assets available at the beginning of the planning period should be valued at their highest marketable value in an alternative use." As for the end of the planning period: "All assets available at the end of the planning period should be valued at their interval value in continued operation or in alternative uses, whichever is higher." Thus, according to Niskanen the planning period is no longer an important question. However, it should be noted that the problems of estimating the value of the assets at the end of the planning period may be as formidable as the task of determining the proper length of the planning period.

Another problem in cost estimation is the estimation of the salvage value of the facility at the end of the analysis period. The salvage value can be positive in the case where the structures can be sold as scrap or negative in the case where there is a removal cost. Thus, the salvage value can either reduce or increase the cost of a given alternative and should be taken into account.

In a discussion of the salvage value of highway improvement projects, Kuhn (*365*) says: "It is important that allowances be made for liquidation of the project at the end of its useful life. There may be positive scrap values (sales of salvageable materials), which should be credited as final gains to the project, or there may be negative ones (for example, removal of structures) and these must be treated as costs. Once more in support of prudence in urban freeway planning, it can be argued that concrete structures, interchanges, etc., are difficult and costly to demolish; therefore, there should be analytical evidence that freeway projects show sufficient economic returns over and above project costs to cover final site clearance costs. Although it is true that many highway projects will retain or even enhance their usefulness in future years, no one should be so presumptuous as to believe that all of the current creations will meet the approval of future generations."

Grant and Oglesby (*361*) suggest a method to handle salvage value in an analysis. They suggest that the analyst determine ". . . the present sum that, invested at compound interest, will produce an amount equal to the salvage value at the salvage date. By subtracting this present sum from the original investment, salvage value is fully recognized in the economy study." It should be noted that the inclusion of the present value of the salvage amount in an analysis as suggested by Grant and Oglesby permits the analyst to consider both positive and negative salvage values, whichever may occur.

Another problem in cost estimation arises if a particular project is so large that it will affect the prices of resources used on that project. This problem has been given little or no attention by most authors. McKean (*333*) presents a more complete discussion.

UNCERTAINTY

Rarely does the analyst have a chance to work on a problem where all the costs and benefits are known. Even when all the costs and benefits are quantifiable, the analyst usually is uncertain as to their actual values.

Fisher (*300*) describes two types of uncertainty. The first is "uncertainty about the world in the future." This group includes items such as technological uncertainty and strategic uncertainty. The second is "statistical uncertainty." Fisher says that the second type occurs because chance elements exist in the real world. He also maintains that the second type is the least troublesome to handle. The first type of uncertainty is usually present in long-run decision problems. He mentions sensitivity analysis, contingency analysis, and *a fortiori* analysis as methods to treat this type of uncertainty.

Contingency analysis is most often used to evaluate military programs, and it may have some merit in highway benefit-cost studies. Arthur D. Little, Inc. (*349*), discusses contingency analysis as related to the evaluation of highway improvement projects. They say in connection with this type of analysis: ". . . with the whole field of transportation coming in for expanded attention, there are possibilities of some major changes occurring in commuting and other travel patterns. Therefore, traffic safety programs should not be too parochially focused on present patterns. In other words, one must try to visualize the various changes that might occur which would have a significant impact on program outcomes, and must take these contingencies into account in estimating the future worth of various investments."

Another method mentioned by Little to deal with uncertainty is *a fortiori* analysis. This method is used primarily in the military, but again may have some use in evaluating highway improvement projects. To utilize this method, ". . . the analyst takes a set of circumstances that appear to be generally unfavorable to a program under evaluation and then compares that program with other possible programs. If the first program emerges as the winner in the unfavorable circumstances, the conclusion emerges, with high confidence, that that program is inexorably best, and there is no need to test it under circumstances that would tend to enhance its rank" (*349*).

If the analyst is uncertain about the values of some key parameters, Fisher (*300*) suggests: "Instead of using 'expected values' for these parameters, the analyst may use several values (say, high, medium and low) in an attempt to see how sensitive the results (ranking of the alternatives being considered) are to variations in the uncertain parameters." This is the essence of sensitivity analysis: changing the values of certain parameters to see what effect this has on the final results. Given that the analyst is not sure exactly what the values of the parameters of various alternative systems will be, sensitivity analysis provides a means to examine the changes in the final results (i.e., which system should be accepted as "best") if these parameters change. The analyst can vary each parameter and see how the final results change. If the final results are not appreciably affected by changes in certain parameters, he need not consider these further. If, on the other hand, the final result varies significantly with variations in other parameters, he should spend more time, money, and energy on such parameters to try to achieve the best possible estimates of their actual values.

Little (*349*) discusses another use for sensitivity analysis. This involves finding a value for the uncertain parameter above or below which the "optimal" alternative may change. For example, ". . . the value of life is often left as an unknown, but it can be very helpful to a decision-maker to know that below a value of X dollars per life one course is optimal, but above X dollars, preference would switch to a different course. Or, one might determine that a particular program would not be worth carrying out unless agreement could be reached that an 'average' life was worth at least so much."

It might be worth mentioning that the finding of insensitivity is just as important as finding sensitivity in the estimates. Pardee (*337*) discusses this in an example taken from the military. His example concerns the sensitivity of various types of propulsion systems used in a weapon. He says: ". . . one might find that it makes very little difference costwise which type of propulsion system is utilized in the future weapon being evaluated. Upon receipt of this information, engineering personnel are then free to select that type of propulsion which can be most easily developed and will operate with the least trouble."

Sensitivity analysis, then, can be a helpful aid to the decision maker either by indicating to him the risks involved in his decision, or by reducing the number of parameters that need further consideration. It will not eliminate or even reduce the uncertainty surrounding the estimates of the various parameters. It will, however, indicate how uncertainty can or cannot affect the final results.

BENEFITS—QUANTIFICATION AND EVALUATION

Probably the most conceptually difficult aspect of benefit-cost analysis is the measure of the benefits of each alternative project or system. When the terminology "cost-effectiveness" is used, the measure is referred to as a measure of effectiveness. The analyst would have a comparatively easy task if all the benefits were known and could be quantified. This is not the usual case. Most benefits are subject to a great deal of uncertainty, and the analyst may not be able to estimate even the likelihood that a benefit may be at any given level. Some benefits and costs are not even subject to quantification. How does the analyst measure the increased security and well being of society? He cannot even measure, let alone place a value on, these benefits.

In view of these problems, the first point that should be noted is that *all* the benefits must be specified and enumerated. If not all benefits are taken into account, the wrong system may be considered "best." This includes all benefits external as well as internal to the system. Also, the objectives should be kept in mind when the analyst decides what the appropriate measures of benefits or effectiveness will be. Levine (*327*) provides an example: In his discussion of Office of Economic Opportunity job training programs in the War on Poverty, he describes some methods to evaluate the various alternatives open to the OEO. One approach was to discount expected lifetime earnings of the trainees and match them against the cost of the program. If the earnings are greater than the costs, the training would be justified. He says that for the purposes of the War on Poverty, an alternative to training would be transfer payments if the costs of training were greater than the discounted expected lifetime earnings of the trainees. "But our objective is not just removal of people from poverty by simple devices such as transfer payments. . . . In this case, therefore, the rationale of transfer payments as an equal-value alternative to training is incorrect. Even if discounted earnings were less than cost we might want to do the training anyhow, because of the social value placed on ending poverty through personal opportunity."

Thus, from Levine's example, the discounted expected lifetime earnings of the trainees substantially underestimate the benefits of the training programs. One of the major objectives of the War on Poverty is to end poverty through the enhancement of personal opportunity. Clearly, the expected lifetime earnings of the trainees is not an adequate measure of the achievement of this objective. The alternative of transfer payments, if some measure of this personal opportunity objective were not included in the analysis, may be given more weight than it actually deserves. The analyst must examine carefully the objectives that he would like the alternatives to attain and use that measure or measures that most adequately indicate the level of attainment of the objectives. This is why the objectives must be clearly and distinctly defined. If the objectives are not precisely stated it will be impossible to determine a suitable measure of the level of their attainment.

As mentioned previously, the most difficult task the analyst faces is what to do with benefits that cannot be quantified. Kazanowski (*324*) notes what he calls the "quantification fallacy," in which ". . . the assumption is made that every criterion pertinent to the evaluation or decision may be quantified." This cannot always be done. Certain factors, no matter how hard the analyst tries, cannot be quantified. If this is the case, the analyst should present his results to the decision maker without the benefit of a quantitative analysis.

If the benefits can be quantified, McKean (*332*) believes that some value can be attached to them. He says: "Some people feel that there are two types of gain or cost, economic and non-economic, and that economic analysis has nothing to say about the latter. This distinction is neither very sound nor very useful. People pay for—that is, they value—paintings as well as shoes, peace of mind as well as aluminum pans, a lower probability of death as well as garbage disposal."

Some authors have suggested the use of quasi or shadow prices as a means to place some value on the various benefits. The use of shadow prices is based (*311*) ". . . on the theory that these prices would represent marketplace values if the marketplace actually existed." Dean and Mantel (*311*) argue: "The cost estimation method of 'quasi-prices' begs the question. If a marketplace does not exist, prices do not exist; and to create market prices out of whole cloth simply substitutes the creator's judgment for that of the missing market." They argue that the analyst should look elsewhere to place values on various benefits. They mention the use of the amounts of money granted to individuals by courts of law as one means of placing value on the benefit received from reducing accidents or deaths.

EXPERT OPINION

One method of dealing with the weighting problem, uncertainty, and unquantifiables is to consult an expert or group of experts who are knowledgeable in the particular field of interest. Wells (*347*) describes five general methods used to consult the experts. One method is for the analyst to consult a single expert. Another method is to consult several experts on an individual basis. Two other methods involve a direct face-to-face confrontation of the experts where discussion is permitted within the group. In one of the face-to-face confrontation methods, the group advises an individual, who makes the decision. In the other method, the group makes the decision. Another method mentioned is the "Delphi technique."

The Delphi Technique

The Delphi technique was developed by Helmer, of the RAND Corporation, in 1964. For a more complete discussion see (*307, 318, 320, 321*). Quade (*342*) says: "The Delphi technique attempts to improve the panel or committee approach in arriving at a forecast or estimate by subjecting the views of individual experts to each other's cirticism in ways that avoid face-to-face confrontation and provide anonymity of opinions and of arguments advanced in defense of these opinions." The Delphi technique eliminates the problems of group dynamics that are present in a face-to-face discussion and (supposedly) permits a consensus. Direct discussion is replaced by a series of questionnaires.

Quade (*342*) provides an example of how this method might be used. Suppose an analyst wants an estimate of the value of some number N. He first asks each expert to place a value on N, independent of the others. The analyst then arranges the various responses in order of magnitude and determines quartiles Q_1, M, and Q_3.

$$\begin{array}{ccccccccccccccc} N_1 & N_2 & N_3 & N_4 & N_5 & N_6 & N_7 & N_8 & N_9 & N_{10} & N_{11} & N_{12} & N_{13} & N_{14} & N_{15} \\ \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow \\ \hline & & & \uparrow & & & & \uparrow & & & & \uparrow & & & \\ & & & Q_1 & & & & M & & & & Q_3 & & & \end{array}$$

Next, the values of Q_1, M, and Q_3 are given to each expert. He is asked to revise his previous estimate, and if his revised estimate is outside the range Q_1 to Q_3, ". . . to state briefly the reason why, in his opinion, the answer should be lower (or higher) than corresponds to the 75 percent majority opinion expressed in the first round."

The results of the second round (that is, the revised values of Q_1, M, and Q_3) are given again to the experts along with the various reasons given in round 2 to either raise or lower the value of N. The reasons are given to the experts in such a way that the anonymity of the respondents is preserved. Quade says that the second round estimates will be less dispersed than the first. The experts are asked to evaluate the reasons given in round 2 and again revise their estimates. If their estimates still fall outside the range Q_1 and Q_3, ". . . the respondent is asked to state briefly why he found unconvincing the argument that might have drawn his estimate toward the median."

A new Q_1, M, and Q_3 are then calculated and the experts are again sent these values as well as the new arguments. They are then asked to make a final estimate of N. The median of these last estimates is used as the estimate of N.

Wells (*347*) discusses the advantages and limitations of the Delphi technique. The advantages he mentions are:

1. The "free and creative thinking" of the experts is not subject to constraint.
2. There is no limit to the number of experts that can be consulted.
3. It eliminates the problems of group dynamics that occur in face-to-face discussions.

He says that the lack of a face-to-face confrontation results in the Delphi technique's most severe limitations. These limitations are:

1. "Ambiguity is always a severe problem in written questionnaires."
2. There is too much time between rounds; the experts may either lose interest or forget the specific context in which they reached their previous decisions.

The Decision Display Panel Technique

Wells (*347*) describes a "decision display panel" technique that is used to consult the experts. This technique ". . . seems to embody all of the advantages of the secret ballot and of the Delphi technique, and avoids all of the disadvantages of both." The technique can be used for groups as large as 12.

Each member of a group of experts controls buttons that operate an electronic panel that is in full view of all. The panel has a separate vertical column of numbers assigned to each participant. No individual knows which column is his, nor does he know which columns correspond to the other experts. At the top of each column a plus or a minus sign can be displayed to show each participant's confidence in his answer. There is a final column to show the average of all the votes.

The problem being discussed is given to the participants in advance to allow for "personal research and preparation." Each expert is then informed of the workings of the decision display panel and is asked to assign a weight to a particular factor. He is also asked to evaluate his own competence on this particular question. Each individual then presses the buttons provided for him and the results are shown on the panel. Each expert votes in secret so that no one knows who voted in which way. Only the results are shown on the panel, together with each expert's self-evaluated competence level (either minus, zero, or plus). A discussion period then follows in which the group can engage in "logical persuasion, bargaining, cajoling, threatening, or any other of its favorite techniques." A final vote is then taken using the same procedure as the first. The new average is then calculated and displayed.

Wells mentions two ways to proceed after this. A raw average can be used as a measure of the final consensus of the group, or the votes can be weighted by using the competence ratings assigned by each expert to his own vote.

He argues that the major advantage of the decision display panel technique is that ". . . free and open communications in the traditional sense can still be permitted to clarify points of confusion or disagreement, while most of the disadvantages of face-to-face discussion can be eliminated." The major disadvantage is that small groups must be used.

Paired Comparisons

Dean and Mantel (*311*) present the "method of paired comparisons." This method permits the analyst, with the help of experts, to change an ordinal ranking system into a cardinal system. An example, borrowed from Dean and Mantel, illustrates how the technique is employed.

Suppose the analyst asked a group of experts to ordinally rank a set of items as to their importance. The ranking is:

D
E
M
A
N
B
K
C
L
F
G

where D is the most important and G is the least important. The analyst now wishes to assign a number to each item as an indication of its relative importance; that is, he wishes to change this ordinal system into a cardinal system.

The analyst asks the experts a series of questions about various combinations of the items. An example of one of these questions is: Do you think that $D + M + A$ is greater than, less than, or equal to $E + N + K + C$? Suppose the results of the series of questions look like this:

$$
\begin{array}{ll}
M + A + N + B & > D + E \\
M + A + N & = D + E \\
A + N & > M \\
A + B & > M \\
N + B & > M \\
B + K + C & = M \\
F + G + L & < N \\
C + L + F & < K \\
F + G & < L
\end{array}
$$

To evaluate these items, arbitrarily assign the top item, D, a value of, say, 100. Since $E < D$, let $E = 90$. Since $M + A + N = D + E$, $M + A + N = 190$. Since $M > A > N$, it follows that $M > \frac{190}{3} = 63$. Now $M < E$, therefore $M < 90$. So $63 < M < 90$. Let $M = 75$. Since $M + A + N = D + E$, then $A + N = 190 - 75 = 115$. Since $M > A > N$, then $75 > A > N$. Let $A = 65$, $N = 50$. Since $N + B > M$, $B > M - N = 75 - 50 = 25$. But $B < N = 50$. So $25 < B < 50$. Let $B = 30$.

This process can be continued for all the items in the set. Dean and Mantel note that this process of repeated questions can also serve as a check on the experts to see if their estimates are really consistent. A method similar to this is discussed in (*309*) and (*302*).

Most authors believe that a cardinal rating scale is necessary in benefit-cost studies, although Fox and Haney (*316*) state otherwise. They argue: "In many situations, we have found that our best approach was to use an ordinal rather than a cardinal rating system to evaluate effectiveness." They go on to say that it may not be possible to estimate all measures on a cardinal ranking system. "It might be more realistic, then, to measure effectiveness on an ordinal scale. Each system under consideration could be rated for any given measure of effectiveness as high, medium, or low, or assigned a rating that is scaled between 1 and 5."

THE MODEL

The next step in most benefit-cost studies is to design some sort of model to represent the system or systems that the analyst wishes to evaluate. This model is necessarily an abstraction, although it should be a reasonable representation of reality. The model can be either highly mathematical in form or merely a verbal description of reality. It can be a computer simulation or a written representation. Fisher (*300*) discusses the model at length. He says: "The main purpose in designing the model is to develop a meaningful *set of relationships* among objectives, the relevant alternatives available for attaining the objectives, the estimated cost of the alternatives, and the estimated utility for each of the alternatives." He says that the model should take uncertainty into consideration also and cautions against the inclusion of too many unimportant factors. In addition, the analyst must "include and highlight" those factors that are important and exclude from the model those factors that are relatively unimportant. He states: "Unless this is done the model is likely to be unmanageable."

The assumptions underlying the model should be made explicit. Fisher (*300*) argues: "Since by definition a model is an abstraction from reality, the model must be built on a set of assumptions. These assumptions must be made explicit. If they are not, this is to be regarded as a defect of the model design."

After the model has been built, it should be checked to ascertain whether it is structured in such a way as to produce a reasonable representation of reality. Fisher states that although the model sometimes cannot be checked by controlled experiment, the analyst may want it to answer the following questions:

1. Can the model describe known facts and situations reasonably well?
2. When the principal parameters involved are varied, do the results remain consistent and plausible?
3. Can it handle special cases where we already have some indication as to what the outcome should be?
4. Can it assign causes to known effects?

DISCOUNTING

When the various costs and benefits appear as a stream over time the analyst's job becomes more difficult. The costs or benefits may be larger in the first time period and decrease thereafter. Or the benefits and costs may grow larger through time, or the benefits may become larger while the costs become smaller. The important point is that both the benefits and costs come in streams that are not necessarily equal, nor are they necessarily the same throughout the years.

If, in Figure E-1, it is assumed that the two alternatives cost the same, which benefit stream is to be preferred? This is a question that the analyst often faces. Discounting can help him answer it.

One of the more controversial aspects of benefit-cost analysis is the use of the discount rate. It is controversial because there is little agreement as to which rate to use. Discount rates from 2 percent all the way up to 25 percent have been suggested by various authors. Some argue that discounting should not be allowed at all in benefit-cost studies. Of course, this argument boils down to the assumption of a zero rate of discount. What follows in this section is a brief discussion of some of the arguments of various authors as to what the proper discount rate should be.

Broussalian (*306*) believes there is no "correct" discount rate that can be used for government investments. He says: ". . . the present value criterion is not economically meaningful in a certain class of decisions; namely, the class of collective consumption decisions. In such cases, the operation of discounting produces a number to which no economic interpretation can be given."

He argues that in the private investment decision the present value of the costs of the investment can be represented as the decrease in consumption opportunities over time. He says: "Since there is a one-to-one correspondence between the present value of costs and the decrease in consumption opportunities, the former may be used as a measure of the latter." He then argues that looking at government investment decisions in this way presents many difficulties. "In what sense can we argue that the present value of a particular stream of resources withdrawn from society by taxation measures the decrease in its consumption opportunities?" He then says that we cannot look at the consumption opportunities of individuals, but must look at the consumption stream of society as a whole. He argues that since the private investment decision can be changed or sold on the market, it makes sense to discount it. Society cannot change its benefit stream after the decision to invest is made. That is, society cannot sell part of the benefits from an investment on the market. Thus, there is no discount rate that is valid.

Niskanen (*336*) takes issue with this argument. He says: "Broussalian . . . argues that the absence of an opportunity to exchange the outputs of military forces at some price eliminates any relevance of the relative price of the inputs in different years. This argument is either wrong or too obscure for me to interpret."

Sobin (*345*) comes to different conclusions than does Broussalian. He states: "An interest rate for money costs is applicable to benefits only in the special case where the benefits are measured in the same units as the costs." By this he means that the analyst cannot discount military capability or deterrence, nor can he discount happiness. Only when benefits are measured in money can they be discounted.

Some authors tend to think that a higher interest rate should be used for riskier investments to reflect the risk involved. Alternatives that realize payoffs in the more distant future are considered more risky. The argument is that unforeseen technological change may eliminate the need for the alternative exhibiting payoffs in the more distant future. A higher discount rate is recommended to reflect the riskiness of these more distant payoffs. Sobin (*345*) rejects this notion. He says: "The correct principle to follow is that risk or uncertainty, if they are considered to be disadvantages of a course of action, should be allowed for explicitly and independently of any application of interest rates."

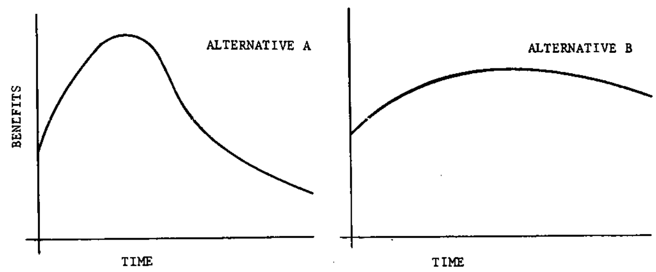

Figure E-1. Example of time distribution for two alternatives.

Sobin then states how the "correct" discount rate should be calculated. He says: "A particular DOD expenditure may conceivably be considered as taking money that would otherwise be available only for other expenditures under the same Congressional appropriation, other expenditures by DOD as a whole, other expenditures by the Government as a whole, or other expenditures by one or both of taxpayers or lenders to the Government. In each of these pools, the marginal utility of a dollar of purchases may differ; and, in general, the ratio between the marginal utility of a dollar of purchases between one period and another period will differ from pool to pool." Thus, he concludes, "The correct discount rate on money for a class of expenditures is the ratio between [the] marginal utilities of the two pools of money . . . from which the expenditures are made." It is worth noting that he does not try to demonstrate how one goes about finding the correct pool to use.

Niskanen (*336*) presents another method to calculate the "correct" discount rate. His argument is summarized by Eskew (*313*), as follows: "He [Niskanen] suggests that the total opportunity cost of government borrowing is the correct discount rate, since debt policy can be used to achieve preferred time profiles of both taxes and borrowing. In estimating the value of this rate to be 10 percent, his calculations assume that additional government borrowing displaces an equal amount of private investment, and therefore, the total opportunity cost is the sum of the direct cost of borrowing; i.e., the interest rate plus the loss of tax revenues associated with society's foregone investment income."

Eskew, of course, has his own ideas about how the proper discount rate should be calculated. He says that even if the interest earning potential of funds is ignored, the government would still be indifferent between an outlay of, say, \$105 million next year and \$100 million now. "It is simply that if a society's income is growing at an annual rate of 5 percent, the burden imposed on that income base by a \$105 million 'tax bite' or budget deficit will be no greater a year from now than would be \$100 million now" (*313*). He then argues that rather than using some interest rate to discount benefit and cost streams, the real growth rate of the economy should be used instead. The real growth rate should be used if estimates of future costs and benefits are made in constant dollars. If the estimates take changes in future price levels into consideration, the unadjusted growth rate should be used.

Eskew then asks which measure of growth should be used. Should it be gross national product, net national product, or personal income? His preference is to select the measure exhibiting the highest rate, because this procedure makes alternative streams look less attractive when their payoffs are to be realized in the more distant future. He says that weighting streams in this way provides some cushion for the possibility that unforeseen changes in technology may eliminate the need for a system's capability prior to the end of the relevant planning period.

If the analyst has examined all the issues involved and still cannot find the appropriate discount rate, Fisher (*300*) suggests ". . . an upper bound rate and lower bound rate may be used to see whether it really makes any difference in the final conclusions of the problem."

Of course, the analyst can always concur with Levine (*327*), who states: "To me, this whole debate is meaningless when estimates of proper interest rates are very imprecise and the final choice of an interest is arbitrary. If a go-no-go decision were made on the basis of such an arbitrary choice of interest rate it would be the wrong decision half the time."

CRITERIA FOR CHOICE AMONG ALTERNATIVES

The next step in the analysis involves choosing a criterion or criteria on which to base a decision as to which alternative system or project is "best." This is one of the more difficult steps in an analysis. McKean (*332*) says: ". . . discussion the correct way to design criteria may seem like discussing the correct way to find the Holy Grail." He goes on to enumerate what he calls "good (though never perfect) criteria," as follows:

1. "Maximum gains minus cost wherever possible." This is referred to as "net benefit." The alternative is chosen that yields the greatest net benefit.
2. "Maximum achievement of an objective for a given cost." Cost is held fixed, and for this level of cost the alternative that yields the greatest benefit is chosen.
3. "Minimum cost of achieving a specified amount of an objective." In this case, benefits are held constant, and the alternative that requires the least cost for this level of benefit is chosen.

Some authors continually search for the alternative that yields the greatest amount of benefit for the least amount of cost. There is no such alternative. Hitch and McKean, quoted in Kazanowski (*324*), elaborate on this point. "Actually, of course, it is impossible to choose that policy which simultaneously maximizes gain and minimizes cost, because there is no such policy. To be sure, in a comparison of policies A and B, it may turn out occasionally that A yields greater gain, yet costs less than B. But A will not also yield more and cost less than all other policies C through Z; and A will, therefore, not maximize yield while minimizing cost. Maximum gain is infinitely large, and minimum cost is zero. Seek the policy which has that outcome, and you will not find it."

Kazanowski (*324*) warns against the "sole criterion fallacy." This is the fallacy that a single criterion can be selected to evaluate all the alternatives. The real world is never this simple. To try to evaluate all of the alternatives on the basis of one criterion is meaningless. This occurs because of the complexities involved in each system and because the systems may differ in many respects.

Some authors have tried to express all the various criteria in terms of one "super criterion." Kazanowski (*324*) provides an example of the errors that may occur if a "super criterion" is used. He says that an electronic system can be made more reliable by using more redundant elements; thus, according to Figure E-2, reliability increases as weight increases. He says, though, that in some cases a system can be made more reliable by simplification; thus, according to Figure E-3, reliability increases as weight decreases.

In many military cost-effectiveness studies, the level of either cost or effectiveness cannot be predetermined. The analyst is not sure which level of either cost or effectiveness is acceptable to the decision maker. One method is to present a whole range of levels of both cost and effectiveness to the decision maker. Fox and Haney (*316*) say: "The analyst evaluating military systems frequently does not have either a fixed budget (cost) constraint or a fixed effectiveness requirement. If he had either, the selection of the preferred system would be conceptually less difficult. Under the assumption of a fixed budget constraint, the analyst would eliminate from consideration all systems but the most effective. Similarly, if the effectiveness level were predetermined, he would attempt to minimize cost. But, in general, the analyst must assume that a range of levels of effectiveness and cost will be acceptable to the decision-maker."

In most benefit-cost studies, the costs and benefits accrue over time. The prices of both the costs and benefits can change over time. The question that arises is: Should the analyst take these changes in price into account when evaluating the various alternatives? Prest and Turvey (*301*) state that the analyst should take into account changes in the relative prices of costs and benefits, but not changes in the general price level. They argue that "the essential principle is that all prices must be reckoned on the same basis, and for convenience this will usually be the price level prevailing in the initial year."

Some of the more commonly used criteria are benefit-cost ratios, net benefit, incremental benefit-cost ratios, and the internal rate of return on investment. Each of these methods is discussed in turn in the following.

Benefit-Cost Ratios

One method used to evaluate the various alternatives is to form a ratio of the benefits and the costs accruing to each alternative project or system, and select the alternative that exhibits the highest benefit-cost ratio. This method of selection has produced a great deal of controversy.

Probably the commonest criticism of the use of benefit-cost ratios is the argument that the ratios ignore the relative magnitude of the various costs and benefits involved. Kazanowski (*324*) provides an example of what is involved with the use of these ratios. In his example, a person is offered a chance to gamble \$0.25 against \$1.00 with a probability of 0.5 of winning. This person may do it, as the possible gain is four times the amount risked. But suppose this person is asked to gamble all of his possessions on a 4-to-1 payoff with the same probability of winning of 0.5. He may need time to think before making such a decision. Kazanowski goes on to say: "Thus the magnitude of what is being risked has a bearing on the acceptability of the risk. The use of ratios ignores the effect of the magnitude of the risk, and hence its acceptability."

Fisher *(300)* states: "The use of ratios usually poses no problem as long as the analysis is conducted . . . with the level of utility or cost fixed." He believes that if either benefits or costs are not fixed, these ratios have no meaning. He cites an example where two alternatives have equal benefit-cost ratios, but have different costs and benefits, as follows:

ALTERNATIVE	BENEFITS	COSTS	BENEFIT-COST RATIO
A	20	10	2
B	200	100	2

Fisher asks if, in this example, the decision maker should be indifferent between the two alternatives. He says that because of such a wide difference in scale between A and B ". . . the analyst might not even be comparing relevant alternatives at all."

Another defect of the benefit-cost ratio method is that ". . . bookkeeping types of decisions can affect the outcome . . ." *(349)*. In the highway field, maintenance costs, for example, can be treated as either positive costs or negative benefits. If the maintenance costs are put in the numerator of the ratio, the ranking of alternatives may differ from the case where these costs are placed in the denominator of the fraction. This is not a problem for the net benefit or incremental benefit-cost ratio method.

The primary advantage of using the benefit-cost ratio method for ranking alternatives is that it can deal with cases in which the benefits and the costs are not expressed in the same units. This advantage is unique to the benefit-cost ratio method when compared to all the other methods previously mentioned.

In most highway benefit-cost analyses, the benefits and the costs are expressed on an annual basis. This is done through the use of the capital recovery factor mentioned earlier in this appendix. Smith *(369)* provides an example of the ratio most commonly used in the highway field, given as:

$$\frac{R_0 - R_1}{S_1 + M_1 - S_0 - M_0} = \frac{R_0 - R_1}{(S_1 - S_0) - (M_0 - M_1)} \qquad \text{(E-3)}$$

in which

$S =$ investment costs on an annual basis;
$M =$ maintenance costs on an annual basis; and
$R =$ road user costs on an annual basis.

The subscripts 0, 1 refer to the existing and the proposed facilities, respectively. It should be noted that the "benefits" of a given highway improvement as expressed in the numerator of the ratio are given in terms of a decrease in road user costs. Most studies of highway improvements calculate benefits in this manner.

Thus, the measure of benefits in the highway field is limited to the reduction in road user costs that would result from a proposed facility. Other benefits of transportation, such as the pleasure of travel, are not considered.

As mentioned previously, the benefits and the costs that accrue because of highway improvement are usually expressed on an annual basis. Grant and Oglesby *(360)* discuss the methodology involved in obtaining equivalent annual benefits and costs, given that there are nonuniform streams involved. They say: "In general, the calculation of a uniform annual figure equivalent to a nonuniform series of future money amounts requires the calculation of the present worth of each money amount. These present worths are added together and the equivalent uniform annual figure is obtained by multiplying the sum of the present worths by the appropriate capital recovery factor."

The benefit-cost ratio of Eq. 3, used so frequently in highway studies, compares all of the alternatives with the existing situation. Grant and Oglesby believe that this constitutes a crucial defect in these ratios. They say *(361)* that these ratios ". . . do not provide a sufficient basis for a choice among alternatives. All of these ratios merely compare a particular proposed location and design with an

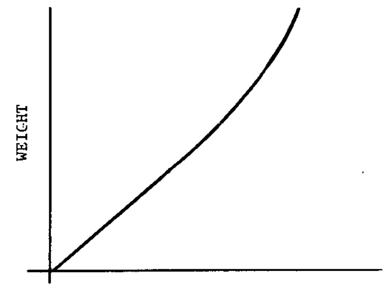

Figure E-2. Reliability increases as weight increases: Kazanowski (324).

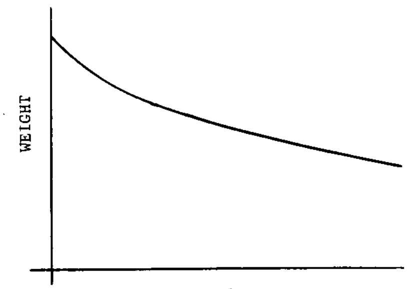

Figure E-3. Reliability increases as weight decreases: Kazanowski (324).

assumed continuation of the present condition; none of the ratios provides a basis for comparing the alternatives with one another."

Net Benefit

The net benefit method requires the analyst to subtract the costs from the benefits of each alternative; the alternative that exhibits the largest net benefit (difference between cost and benefit) is selected. Looking at this in terms of production theory, total benefits can be considered the same as total revenue, total costs have the same meaning, and net benefit can be considered as total profit. Maximizing net benefit then corresponds to the firm maximizing total profit.

Use of benefit-cost ratios to evaluate the various alternatives does not always lead to the same alternative being chosen, as would use of net benefit if there is a large disparity between the costs and benefits of the various alternatives. For example:

ALTERNATIVE	BENEFITS	COSTS	BENEFIT-COST RATIO	NET BENEFIT
A	200	100	2	100
B	30	10	3	20

In this example, Alternative A will be chosen if the analyst uses net benefit as the criterion of choice, but alternative B will be chosen if the benefit-cost ratio method is used. If a firm used the principle of the benefit-cost ratio as the criterion to decide at which level of output it should produce, it is unlikely that the firm would be maximizing profit. The one defect in the net benefit method is that it cannot handle situations in which the costs and benefits cannot be expressed in the same units.

Incremental Benefit-Cost Ratios

A third method frequently mentioned in the literature as a criterion of choice is the incremental benefit-cost ratio. A simplified example illustrates how this method works. Assume that a highway agency must pick one alternative from among ten mutually exclusive alternatives. There is no budget limitation, because the highway agency has funds available to cover the cost of any one of the ten alternatives being considered. For convenience of illustration, it is assumed that none of the alternatives is dominated by any other (that is, is overshadowed by reason of another being any more effective while costing the same or less). The various alternatives are ranked by increasing cost in Table E-1. The essence of the method is to examine the ratio:

$$\frac{B_{k+1} - B_k}{C_{k+1} - C_k} \tag{E-4}$$

If this ratio is greater than 1, alternative A_{k+1} is accepted and compared with alternative A_{k+2} in the same manner. If the ratio is less than 1, A_k is accepted and compared with A_{k+2}. These comparisons are continued until the last acceptable alternative is reached. This alternative is accepted as best. Table E-2 illustrates the method.

In this example, alternative A7 is considered best. In this situation the incremental analysis leads to the same alternative being chosen as for the net benefit method. This can be readily seen, for, if $\frac{(B_j - B_i)}{(C_j - C_i)} > 1$, $(B_j - B_i) > (C_j - C_i)$ and $(B_j - C_j) > (B_i - C_i)$. The incremental benefit-cost ratio method for ranking alternatives suffers from the same defect as the net benefit method. That is, it cannot handle situations where the benefits and the costs are expressed in different units.

Ratios and Net Benefit—A Comparison

It might be helpful to examine the relationships that exist among the benefit-cost ratio method, the net benefit method, and the incremental benefit-cost ratio method for ranking the alternative projects or programs. The benefits and the costs of six alternatives are shown in Figure E-4, in which the origin represents the existing situation. The benefits that accrue to alternative A2 can be represented by the line segment A2 — C_2. The costs accruing to this alternative are represented by the line segment A0 — C_2.

TABLE E-1

EXAMPLE OF COSTS AND BENEFITS OF ALTERNATIVE PROJECTS

ALTERNATIVE	BENEFIT, B	COST, C	$B-C$
A1	10	2	8
A2	20	14	6
A3	50	25	25
A4	80	30	50
A5	90	45	45
A6	100	70	30
A7	140	75	65
A8	170	130	40
A9	220	160	60
A10	350	320	30

TABLE E-2

EXAMPLE OF INCREMENTAL METHOD OF SELECTION OF BEST ALTERNATIVES

COMPARISON	INCREMENTAL BENEFITS	INCREMENTAL COST	INCREMENTAL BENEFITS/COST	DECISION IN FAVOR OF
A1 vs A0	10	2	5	A1
A2 vs A1	10	12	5/6	A1
A3 vs A1	40	23	40/23	A3
A4 vs A3	30	5	6	A4
A5 vs A4	10	15	2/3	A4
A6 vs A4	20	40	1/2	A4
A7 vs A4	60	45	4/3	A7
A8 vs A7	30	55	6/11	A7
A9 vs A7	80	85	16/17	A7
A10 vs A7	210	245	6/7	A7

The benefit-cost ratio, then, is $(A2 - C_2)/(A0 - C_2)$; but this is nothing more than the tangent of the angle $A2 - A0 - C_2$. As this angle increases, its tangent increases; or, as the angle increases, the benefit-cost ratio increases. Conversely, as the benefit-cost ratio increases, the angle increases. The tangent function is ever increasing in the interval 0° to 90°. Thus, choosing the alternative that exhibits the largest benefit-cost ratio corresponds to picking the alternative whose ray from the origin is the highest. The 45° line indicates where the benefits are equal to the costs. All along this line the benefit-cost ratio is 1.0, as should be expected, because $\tan 45° = 1$. For all the alternatives above the 45° line the ratio is greater than 1.0; for those below this line, less than 1.0. The benefit-cost ratio solution would indicate indifference between alternatives A1 and A3, because they both lie on the highest ray from the origin.

Net benefit in this figure is represented as the vertical difference between the 45° line and the alternative. As can be seen clearly, all the other alternatives are dominated by alternative A3. Alternative A5 has a negative net benefit and a benefit-cost ratio less than 1.0.

The same six alternatives are shown in Figure E-5. The incremental benefit-cost ratio in this figure is represented as the line segment that joins two alternatives; thus, the incremental benefit-cost ratio in going from project A1 to project A2 is the line segment A1 — A2. Now, the criterion of choice using the incremental benefit-cost ratio procedure is that if the ratio is greater than 1.0, the alternative exhibiting the greater cost is accepted over the other. For alternative A1 as compared to alternative A2, a ratio of 1.0 can be displayed as the 45° line originating at point A1. So, if the incremental benefit-cost ratio is greater than 1.0 it will be above the 45° line; if it is less than 1.0 it will be below the 45° line. But the increment in going from A0 to A1 is greater than 45°, so A1 is considered better than A0. The increment in going from A1 to A2 is also greater than 45°, so A2 is accepted over A1. This procedure is continued for all the alternatives. As can be seen from the figure, alternative A3 is accepted as best by this criterion because a line segment joining A3 to any other alternative will be below the 45° line originating at point A3. Notice also that alternatives A5 and A6 are below the 45° line originating at alternative A1. There is no need to compare them to any other alternative because A1 is better than either of these two and any other alternative that is better than A1 will be better than either of them.

Again, the same six alternatives are shown in Figure E-6. As is evident from the diagram, the 45° line extending from each alternative merely projects the net benefit for each alternative and compares it to the net benefit of the other alternatives. That is, the vertical distance from the 45° line coming out of the origin is the net benefit that accrues when alternative A1 is employed. When, for example, A1 is compared to A2 by the incremental procedure, the 45° lines become the references to decide if one alternative is better than the other. If A2 were on the 45° line through A1 it would have the same net benefit as A1. Because A2 is better than A1 it lies on a higher 45° line than the corresponding parallel line through A1. This means that the net benefit for A2 is greater than that for A1. It should be clear from these three diagrams that the net benefit

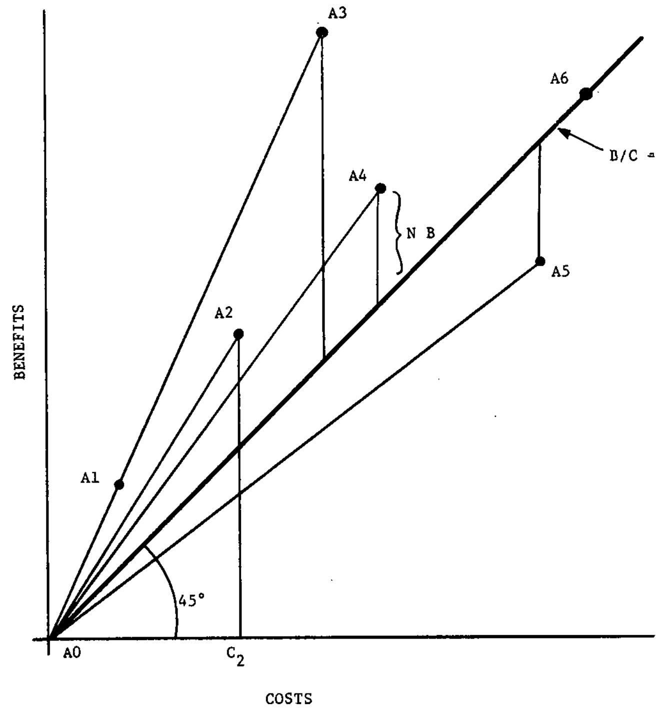

Figure E-4. Example of the benefit-cost ratio solution.

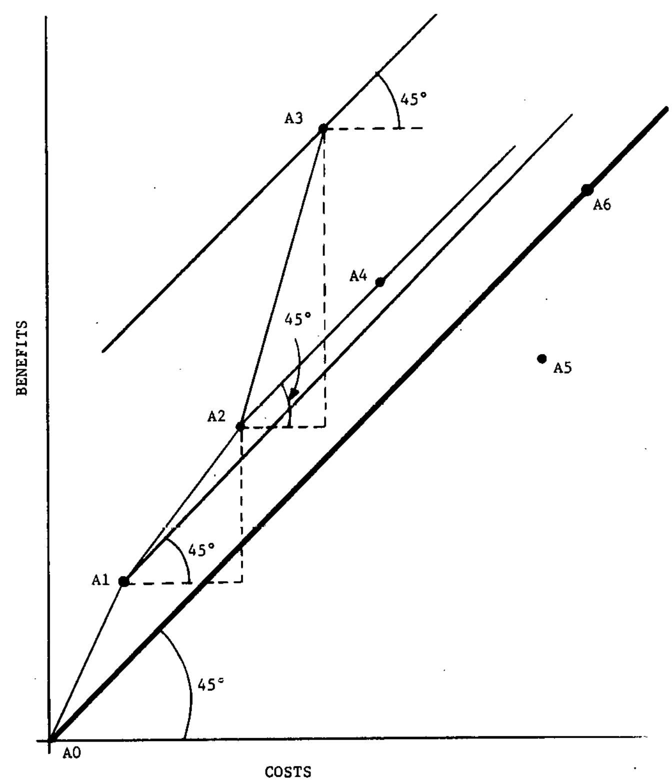

Figure E-5. Example of the incremental benefit-cost ratio solution.

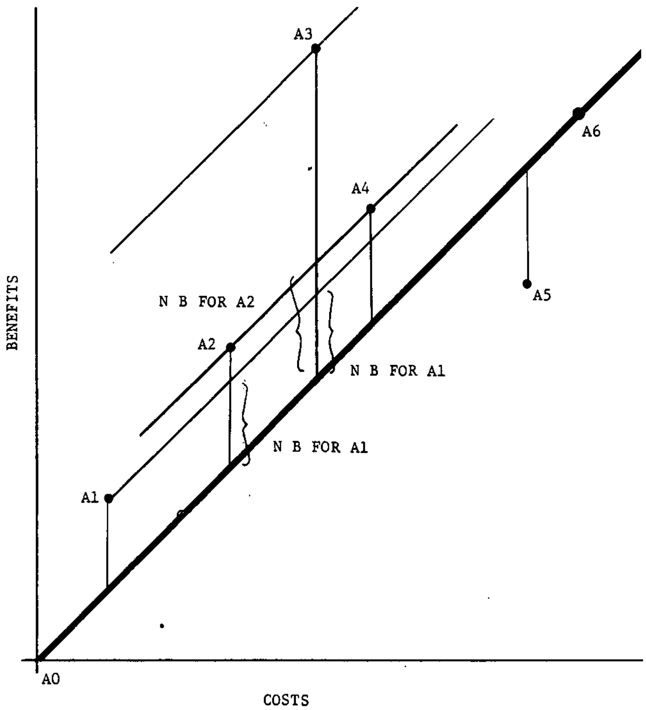

Figure E-6. Example of the net benefit solution.

solution is equivalent to the incremental solution and the benefit-cost ratio solution need not necessarily be the same solution as the other two.

Rate of Return

The fourth criterion mentioned previously to evaluate the various alternatives is the rate of return method. Smith (*369*) says: "The rate of return can be computed by simply equating annual savings with annual costs of obtaining such savings."

Annual savings is given by $(R_0 - R_1) - (M_1 - M_0)$ and anual costs are given by $(I_1 - I_0)\ K(i, n)$. Thus, the rate of return is obtained by solving for i in

$$(R_0 - R_1) - (M_1 - M_0) = (I_1 - I_0)\ K(i, n) \quad \text{(E-5)}$$

in which $K(i, n) =$ the capital recovery factor,

$$K(i, n) = \frac{i(1 + i)^n}{(1 + i)^n - 1} \quad \text{(E-6)}$$

$R =$ road user costs on an annual basis;
$M =$ maintenance costs on an annual basis;
$I =$ initial investment;
$n =$ the life of the project, in years; and
$i =$ the rate of return.

The alternative that produces the highest rate of return is accepted as best.

Grant and Oglesby (*361*) take issue with the use of the rate of return method. They say: "Prospective rates of return for a number of alternatives as compared to continuing a present condition do not provide an adequate basis for comparing these alternatives with one another." They propose using the incremental rate of return method instead. This method is similar to the incremental benefit-cost ratio method discussed previously.

Additional Considerations

The criteria examined so far have been discussed in the context of the analyst wanting to choose one alternative project or program from a group of alternatives, with the budget requirement not held fixed. Various criteria were mentioned to assist in choosing that project which is "best." Throughout much of the literature on benefit-cost analysis there exists a general consensus that what the analyst should seek to maximize when he chooses one alternative is the difference between the benefits and the costs. Returning to the production theory analogy, this criterion corresponds to the firm maximizing profit. In the situation just discussed, it should be clear that either the difference criterion or the incremental benefit-cost ratio criterion will maximize net benefit. The other two criteria will not always accomplish this objective.

There exist situations, however, when the use of either the difference criterion or the incremental benefit-cost ratio criterion will not necessarily lead to a maximization of net benefit. There are other situations in which not only will the net benefit and incremental benefit-cost ratios lead to the maximization of net benefit, but the ratio criterion also will accomplish this objective. For example, it can be easily demonstrated mathematically that all three criteria will lead to a maximization of net benefit when the level of either cost or benefit is held fixed.

An interesting situation occurs when a highway agency with a fixed budget wishes to choose a set of projects from a larger set. A simple example shows that the use of the benefit-cost ratio as the criterion of choice usually leads to a higher total net benefit from the set than do the other two criteria. This happens because the ratio criterion favors lower cost alternatives and the other two favor projects that have a higher net benefit, and usually a higher cost.

Another situation that has been discussed in the literature is where a highway agency has under consideration a set of projects at a set of locations with a fixed budget. The analyst's job is to pick the set of projects that will be best. Widerkehr (*373*) discusses this situation at length.

He assumes that three highway locations are being considered for improvement; also, that three alternative projects can be used at each location, as given in Table E-3. The decision maker's job is to select the combination of projects that will yield the greatest net benefit. Not more than one project can be applied at each location and the budget is fixed at $3. Widerkehr states: ". . . the net benefit is not in general maximized if one selects the project at each location with the largest benefit-to-cost ratio."

If the analyst selects the project at each location with the largest benefit-to-cost ratio, project 1 would be selected at each location. This would yield a total benefit of 22 and a net benefit of 19. If, however, project 2 was chosen for location 1 and project 1 was selected for location 2, total benefit would be 25 and net benefit would be 22. Wider-

TABLE E-3

EXAMPLE OF EVALUATION OF ALTERNATIVE PROJECTS; WIDERKEHR'S METHOD

LOCATION	PROJECT	COST, C	BENEFIT, B	B/C	$B-C$	$\Delta B/\Delta C$
1	1	1	10	10	9	10
	2	2	17	8.5	15	7
	3	3	23	7.67	20	6
2	1	1	8	8	7	8
	2	2	11	5.5	9	3
	3	3	12	4	9	1
3	1	1	4	4	3	4
	2	2	6	3	4	2
	3	3	7	2.3	4	1

kehr says: "The reason for this improvement is that the ratio of the incremental benefit to incremental cost in going from project 1 to project 2 at location 1 exceeds the benefit-to-cost ratio for project 1 at location 3."

Widerkehr presents a series of steps for the analyst to follow so as to arrive at the optimum set of projects for a fixed budget, allowing at most one project at each location.

1. "At each location consider only projects not dominated by other projects.
2. "Select a 'critical value' for the ratio of incremental benefit to incremental cost and select the project at each location with the greatest cost and with incremental benefit-to-cost ratios exceeding the selected critical value.
3. "Compute the corresponding total cost.
4. "If this cost exceeds the funds available for the single time period, increase the critical value; if this cost falls short of the available funds, decrease the critical value.
5. "Repeat steps 3 and 4 until the computed total cost is as close as possible to the funds available for the single time period."

Haney (*364*) also provides a method to handle this situation using incremental benefit-cost ratios. Table E-4 gives four locations with various alternatives for each. The analyst's job is to pick that set of projects which is "best," given a budget constraint of 135. The essence of this method is to order the alternatives at each location by increasing cost. At each location, the incremental benefit-cost ratios for each alternative as compared to the "do nothing" alternative are then calculated. The analyst then calculates the incremental benefit-cost ratio for each alternative against all other alternatives at each location. The results are given in Table E-5. Next, the analyst must examine the incremental benefit-cost ratios at each location for each alternative as compared to alternative A0. The alternative that exhibits the highest ratio as compared to all other alternatives at all other locations is then accepted. This is alternative 2 at location 4, inasmuch as its ratio as compared to alternative A0 is the largest of all. So, alternative 2 at location 4 is entered at the top of Table E-6 with a cost of 20, which brings the total cost to the highway agency to 20.

TABLE E-4

EXAMPLE OF COSTS AND BENEFITS OF ALTERNATIVE PROJECTS GROUPED BY LOCATION

LOCATION	ALTERNATIVE	COST, C	BENEFIT, B	B/C	$B-C$
1	1	10	30	3	20
	2	15	45	3	30
	3	20	50	2.5	30
2	1	20	30	1.5	10
	2	25	40	1.6	15
	3	40	60	1.5	20
	4	60	100	1.67	40
3	1	25	50	2	25
	2	30	60	2	30
	3	50	65	1.3	15
	4	60	90	1.5	30
4	1	10	50	5	40
	2	20	150	7.5	130
	3	30	210	7	180

TABLE E-5

EXAMPLE OF INCREMENTAL BENEFITS AND COSTS

LOCATION	COMPARISON	ΔB	ΔC	$\Delta B/\Delta C$
1	A1 vs A0	30	10	3
	A2 vs A0	45	15	3
	A3 vs A0	50	20	2.5
	A2 vs A1	15	5	3
	A3 vs A1	20	10	2
	A3 vs A2	5	5	1
2	A1 vs A0	30	20	1.5
	A2 vs A0	40	25	1.6
	A3 vs A0	60	40	1.5
	A4 vs A0	100	60	1.67
	A2 vs A1	10	5	2
	A3 vs A1	30	20	1.5
	A4 vs A1	70	40	1.75
	A3 vs A2	20	15	1.33
	A4 vs A2	60	35	1.71
	A4 vs A3	40	20	2
3	A1 vs A0	50	25	2
	A2 vs A0	60	30	2
	A3 vs A0	65	50	1.3
	A4 vs A0	90	60	1.5
	A2 vs A1	10	5	2
	A3 vs A1	15	25	0.6
	A4 vs A1	40	35	1.14
	A3 vs A2	5	20	0.25
	A4 vs A2	30	30	1
	A4 vs A3	25	10	2.5
4	A1 vs A0	50	10	5
	A2 vs A0	150	20	7.5
	A3 vs A0	210	30	7
	A2 vs A1	100	10	10
	A3 vs A1	160	20	8
	A3 vs A2	60	10	6

TABLE E-6

EXAMPLE OF STEPWISE SELECTION OF BEST ALTERNATIVES; HANEY'S METHOD

LOCATION	ALTERNATIVE	COST	TOTAL COST
4	2	20	20
4	3	30	30
1	1	10	40
1	2	15	45
3	1	25	70
3	2	30	75
3	4	60	135

TABLE E-8

RESULTS OF ALTERNATIVE SELECTION BY WIDERKEHR'S METHOD

	ALTERNATIVE	
LOCATION	TRIAL 1	TRIAL 2
1	2	2
2	0	4
3	4	4
4	3	3
(Total cost)	105	165

The analyst then compares the incremental benefit-cost ratios of all alternatives at all locations with A0, except in the case of location 4 alternative 2, already chosen, where the analyst examines the ratio of A3 to A2. As can be seen from Table E-5, the ratio of A3 to A2 at location 4 is 6, which is larger than the incremental ratios at the other

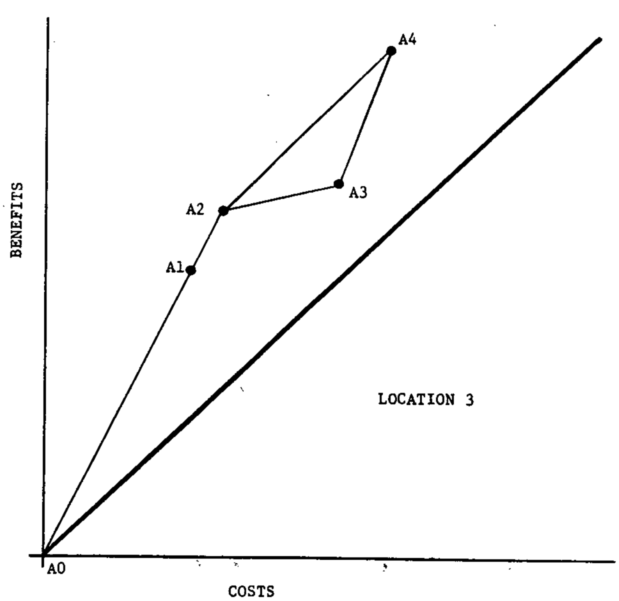

Figure E-7. A comparison of the Haney and Widerkehr methods.

TABLE E-7

EXAMPLE OF FINAL SOLUTION, BEST ALTERNATIVES; HANEY'S METHOD

LOCATION	ALTERNATIVE
1	2
2	4
3	2
4	3

three locations when the alternatives at these locations are compared with A0. So, alternative 3 at location 4 is accepted and entered in Table E-6. However, this alternative displaces alternative 2 at location 4, so the total cost to the highway agency stands at 30. Location 4 need not be considered any further.

Next, the analyst considers the incremental ratios of all the alternatives at the other three locations as compared to A0. Alternative 1 at location 1 has a ratio of 3 and is tied with alternative 2 at that location. In this case, A1 will be accepted because it is less costly than A2. So, alternative 1 at location 1 is entered in Table E-6 with a cost of 10, which brings the total cost to the highway agency to 40. The analyst then considers the incremental ratios at the other two locations with A0 and compares these to the ratios of A2 to A1 and A3 to A1 at location 1. The ratio of A2 to A1 at location 1 is 3, which is larger than the other comparisons examined. So, alternative 2 at location 1 is entered in Table E-6, and, because it displaces alternative 1 at the same location, the total cost to the highway agency becomes 45. This procedure is continued until the budget is exhausted or until there exist no other alternatives with incremental ratios of 1 or greater. The results are given in Table E-7.

Haney (*364*) provides a list of steps for the analyst to follow when using this procedure. These steps are as follows:

1. "Given the existing situation at the end of the previous iteration, the incremental investment opportunities not yet chosen or rejected are considered. The measure of each alternative is the incremental benefit-cost ratio.
2. "From all incremental benefit-cost ratios at all locations, the most attractive alternative (that with the greatest benefit-cost ratio) is selected.
3. "The highway cost of the alternative selected is added to a cumulative total highway expenditure schedule. If the alternative selected replaces one at the same location chosen in a previous iteration, the highway cost of the previously chosen alternative is dropped from the highway expenditure schedule.
4. "If the revised highway expenditure total is less than the budget, the alternative chosen at this iteration is added to the list of alternatives previously selected, and any previous selection at that location is removed from the schedule.
5. "If the revised highway expenditure total exceeds the budget, the alternative selected is rejected at this iteration.

The list of alternatives remains the same as at the beginning of the iteration."

It may be helpful to use Widerkehr's method on the situation given in Table E-4 to see if there is any difference in the two methods. The results using this method are given in Table E-8. There is no solution at the 135 budget level; there are only the two alternatives given, depending on whether the highway agency is willing to spend more or less than the budget allocated for these locations. It might be interesting to note that using the Haney method, total net benefit for the set of projects chosen equals 280 for a cost of 135. Using the Widerkehr method, the net benefit is 240 for a cost of 105 and 280 for a cost of 165. It seems that, in this situation at least, the method used by Haney leads to a better set of projects being chosen than does the Widerkehr method.

Figure E-7 illustrates the two methods for location 3. As a first step, the Haney method examines the ratios for all alternatives as compared to A0. The "best" alternative at each location at this iteration is the alternative with the highest benefit-cost ratio. For location 3 this highest ratio is represented as the line segment A0 — A1. The next step is to calculate the incremental ratios of each alternative as compared to all other alternatives. If in an iteration location 3 is chosen, alternative 1 will be picked because it has the highest benefit-cost ratio as compared to A0. If, in another iteration, location 3 is again chosen, alternative 2 will be picked because it has the highest ratio as compared to A1. If in another iteration location 3 is chosen, alternative 4 will be picked because it has the highest ratio as compared to A2. A3 will never be chosen at this location by the Haney method. Thus, the relevant alternatives to be considered by this method are A0, A1, A2, and A4. A map of the path of choice at this location is shown in Figure E-7. The line segment A0 — A1 represents the ratio of best alternative as compared to A0. The line segment A1 — A2 represents the ratio of the best alternative at the second iteration. The line segment A2 — A4 represents the ratio of the best alternative at the third iteration. Thus, the map of the Haney solution for this location is given by the line segments that join the points A0, A1, A2, A4. Only these alternatives are considered by this method.

Of crucial importance in Widerkehr's method is also the incremental benefit-cost ratio. This method, however, only examines the ratios of A1 to A0, A2 to A1, A3 to A2, and A4 to A3. The map of the incremental ratios used in the Widerkehr solution for location 3 is shown in Figure E-7 as the line segments that join the points A0, A1, A2, A3, A4. Now, this method instructs the analyst to select a critical value for the incremental benefit-cost ratio and to ". . . select the project at each location with the greatest cost and with incremental benefit-to-cost ratios exceeding the selected critical value" (*373*). For location 3, if the selected critical value is less than 2.5, A4 will be chosen. If the critical value is 2.5 or greater, A0 will be chosen. This occurs because A4 is the greatest cost alternative and has the greatest incremental ratio when the ratios are calculated in accordance with the Widerkehr method. Notice that A4 has the same benefit as A2; but, according to this method, it is seen to be a much better alternative. This occurs because A3 is not a good alternative, but is not dominated. The incremental ratio of A3 to A2 is only 0.25, and when this alternative is compared to A4, A4 is seen to be much better than it really is. Thus, the Widerkehr method sometimes makes an alternative seem more attractive than it really is.

SUBOPTIMIZATION

Another problem that occurs frequently in benefit-cost studies is that it is sometimes difficult for the analyst to relate how well the various alternatives attain the stated objectives. Suppose a hypothetical family wishes to perform a benefit-cost analysis to ascertain the optimal combination of goods and services to buy so as to maximize happiness. Happiness, then, is the family's stated objective. Of course, it is very difficult, if not impossible, to decide which combination of goods and services will maximize happiness. It may be impossible even to quantify the degree to which happiness is attained through the use of one good or another. In other words, although a utility function for the family may exist, in practice it is impossible for the analyst to decide its exact form.

To get out of this difficulty, the family might try to formulate new objectives whose attainment could be more easily calculated and whose attainment may be an indication of the attainment of happiness. The family, in this case, is said to be "suboptimizing" or optimizing on a lower level. Some of these new objectives that the family may try to attain are the satisfaction of hunger and thirst, the attainment of more leisure time, and the attainment of shelter from the extremes of temperature. These new objectives are referred to as lower-level objectives, and happiness can be referred to as the higher-level objective.

Suboptimization occurs when objectives are subclassified and apportioned to a lower level. McKean (*331*) defines suboptimization as ". . . the process of choosing among a relatively narrow list of operations or resource allocations by an administrative level other than the highest." In the governmental decision process, this involves distributing decisions among the various agencies and departments of the government. For example, if the objective of government is to promote social welfare, the government suboptimizes when it grants its highway department the jurisdiction over highways. The goal of the highway department may be to reduce the cost of transportation along the highways in its jurisdiction. The higher-level objective then, is to promote social welfare; the lower-level objective is to reduce the cost of highway transportation. It would be difficult indeed for the highway agency to relate various courses of action to the higher-level objective. This lower-level objective is then used to relate the decisions of the highway agency to this higher-level objective. Hitch (*322*) states that "operations researchers have to suboptimize (use low-level criteria) because it is so frequently impossible, either in principle or more frequently in practice, to calculate the consequences of any given action in terms of the appropriate high-level criteria."

Whenever the analyst suboptimizes, it is important for him to understand and state how the attainment of the lower-level objectives is an indication that the higher-level objectives are attained. Fox and Haney (*316*) state: "If lower measures of effectiveness are used, it is important that the analyst recognize a relationship between those measures and the higher measure of effectiveness although it may not be possible to define the relationship in a precise quantitative fashion. The analyst should describe—at least in general terms—how an increase in effectiveness using the lower measure as a standard would result in an increase in the higher measure. The analyst should also determine, as explicitly as possible, disparities between the higher and lower measures of effectiveness."

Hitch (*322*) provides an example where the lower-level goals are inconsistent with the higher-level goals. During World War II, convoys across the Atlantic were being attacked by German U-boats. The analyst was assigned to find the optimal convoy size and number of destroyer escorts to maximize the ratio of enemy losses, measured in U-boats, to U.S. losses measured in merchant ships. It was found that this ratio became larger, the larger the convoy size and the more destroyer escorts assigned to it. The U.S. increased the convoy size, and thus deployed more escorts, and it became very unprofitable for the enemy to send U-boats into the Atlantic. The enemy moved its U-boats elsewhere where it became more profitable.

But a higher-level objective was at stake. This was the probability of winning the war. Hitch says that ". . . it is certain that allied operations elsewhere were adversely affected by the diversion of the U-boat fleet." He goes on to say that the ". . . low-level suboptimization criterion is not good enough. Effects must be assessed at least at the next higher level, in terms of the operation or function which we are defending."

Hitch says: "The criterion for 'good' criteria . . . is always consistency with a 'good' criterion at a higher level." In the convoy example, ". . . the test of the exchange rate between U-boats and M/V's [merchant vessels] as a suboptimization criterion in the convoy problem was consistency with the higher-level criterion of probability of victory: and there proved to be, in the general case, no necessary connection." He then says: "Where for practical reasons of convenience, a suboptimization criterion must be used, which is known to be inconsistent with a higher-level criterion, allowance must be made, explicitly or intuitively, for gains or losses imposed on other operations related to the higher-level criterion."

Another example of the lower-level goals being inconsistent with the higher-level goals occurs in an evaluation of highway improvement projects. This example concerns the evaluation of commercial vehicle travel time and is discussed in the beginning of Section II of this appendix.

ADVANTAGES AND LIMITATIONS OF BENEFIT-COST ANALYSIS

Quade (*339*) says that one of the big limitations of cost-effectiveness is ". . . the necessity that measures of effectiveness be proximate." He goes on to say: "We can't be as confident that our estimates of effectiveness are essentially correct as we are about our cost estimates." Another limitation mentioned by Quade is incompleteness. "Limitations on time and money obviously place sharp limits on how far an inquiry can be carried."

Knorr (*325*) says: ". . . the usefulness of the technique is the more limited, the less the problem is capable of uniform quantification." He goes on to say: "A second great limitation of the C E [cost-effectiveness] approach results from imperfect information."

Another limitation mentioned by Quade (*339*) is ". . . that analysis can never treat all the relevant factors. No matter how thorough, it always leaves something for the decision-maker."

In view of all these limitations, Quade (*340*) concludes that an analysis ". . . can do little more than assess some of the implications of choosing one alternative over another. In practically no cases, therefore, should the analyst expect to demonstrate to a decision-maker that, beyond all reasonable doubt, a particular course of action is best."

Levine (*327*) believes that an analysis should be used to discover large quantitative differences among alternatives, not to make decisions based on small quantitative differences among alternatives. He says: "For one thing the numbers used in systems analysis are always imperfect and to make decisions on the basis of small quantitative differences derived from very fuzzy inputs is wrong and is dangerous. If differences are small, then an entirely different basis for decision should be arrived at. Indeed, if quantitative results do not accord with one's intuition, one had better check his numbers very carefully, because by and large intuition is the better guide."

Many authors believe that, in view of its limitations, benefit-cost analysis should be used only as an aid to the decision maker. It should not be used to make the decision for him. Fisher (*300*) says that "In reality most major long-range planning decision problems must ultimately be resolved primarily on the basis of intuition and judgment. We suggest that the main role of analysis should be to try to sharpen this intuition and judgment. In practically no case should it be assumed that the results of the analysis will make the decision."

Even if the analysis should not be used to make the decision, it is an important part of the decision process. If used as an aid to the decision maker, it is probably the best aid that he has. Bell (*304*) says: "There is no substitute for experiment, experience, intuition, and judgment, all of which still can lead to wrong answers. The identification, quantification, and systemization of cost-effectiveness analyses can, however, add to the likelihood that the judgment-decision is a good one."

If nothing else, the analysis can eliminate the really bad alternatives and give the decision-maker a shorter list to choose from. Fox and Haney (*316*) state: "One task of the analyst, then, is to determine which systems need not be considered by the decision-maker because there are alternatives that either cost no more and are more effective, or cost less and are at least as effective."

Quade (*339*) sums up the advantages of benefit-cost analysis when he says: ". . . it is able to make a more systematic and efficient use of judgment than any of its alternatives."

II. QUANTIFICATION AND EVALUATION OF BENEFITS OF HIGHWAY PROJECTS

As stated in the first section of this appendix, a good benefit-cost analysis takes into consideration all the relevant costs and benefits. In the highway field, on the benefit side, this involves the complete enumeration and specification of all the benefits that accrue to users as well as nonusers, benefits that are easily quantified, and benefits that do not lend themselves readily to quantification. It includes the enumeration of market as well as extra-market consequences. This does not imply, of course, that all benefits must be quantified, nor does it imply that all benefits must have some value attached to them. What it does imply is that no prospective source of benefit should go unnoticed in the analysis.

In the highway field, the beneficiaries of highway improvement are usually categorized as users and nonusers. User benefits can occur as a decrease in the cost of motor vehicle operation, a decrease in time spent on the highway, a decrease in accident rates, or a decrease in the strain and discomfort of nonuniform driving. Nonuser benefits can accrue as an increase in land values, stimulation of economic growth along a new roadway, decrease in the cost of transportation-intensive goods, or an increase in the efficiency of delivery of transportation-intensive goods.

As stated earlier, the analyst must keep the objectives in mind when he decides what the appropriate measures of benefits will be. It is assumed throughout this discussion that one of the objectives of highway improvements is the promotion of social welfare. It is further assumed that highway improvement promotes social welfare either through the reduction of the amount of real input required to obtain a stated level of transportation services or through an increase in transportation services for a stated level of inputs. What is measured then, is how the productive capacity of the economy has increased through highway improvement. Mohring and Harwitz (*350*) argue: "By lowering costs and hence reducing the resource requirements per unit of highway transportation, highway improvements release resources which can be used to expand the output of transportation and/or other goods and services. In short, highway investments, like all other productive investments, make it possible to expand the output of the economy."

Many highway improvements result not only in an increase in the productive capacity of the economy, but also in a redistribution of income from one group in the economy to another. Many highway studies fail to take this redistribution of income into account. An example of counting a transfer of income as a benefit occurs in the valuation of time savings that accrue to commercial vehicles. One method to value these time savings is to assume that these savings will permit the same level of transportation services to take place with less inputs. One of the inputs that is decreased is the number of trucks engaged in these services. Thus, the commercial vehicle owners need a smaller fleet of trucks to do the same amount of work. Included as benefits would be not only the cost to the owners of the trucks they did not have to buy, but also the decrease in interest charges on the trucks. However, interest charges in no way constitute a using up of real goods and services for the economy as a whole. They are merely a transference of income from the commercial vehicle owners to the lenders of money. Thus, the inclusion of interest charges as a benefit is not consistent with the previously stated objective. Of course, if the goal of the highway agency is limited to the reduction of the cost of operation of commercial vehicle owners, a reduction in interest charges is a valid benefit to include in an analysis. This, however, is an example of the lower-level objective being inconsistent with the higher-level goal.

USER BENEFITS

Elements of Operating Costs

The first type of user benefit discussed is benefit due to a decrease in motor vehicle operating costs. These costs can be decreased by highway improvement through a decrease in the consumption of fuel and oil, a reduction in tire wear, a decrease in maintenance and repairs, and a reduction in ownership costs. These operating costs differ for different types and conditions of roadway. Some of the more relevant factors that the analyst should take into consideration when measuring these operating costs are the number and arrangements of lanes, the type of roadway surface, the amount of grade along a road, the average running speed, the traffic volume, the alignment of the roadway, and whether the roadway is located in a rural or an urban area.

Fuel Consumption

One of the largest single components of vehicle operating cost is fuel consumption. Not all highway improvements will cause a decrease in this cost. Claffey (*355*) says: "A decrease in the number and frequency of accelerations, number and steepness of grades, degree of road roughness and amount of curvature decreases fuel consumption at any given running speed. On the other hand, highway improvements which result in higher operating speeds such as lane widening, an increase in the number of lanes, resurfacing, and sight distance improvement, usually bring about increased fuel consumption." He goes on to say that a reduction in situations where the vehicle must stop can lead to a decrease in fuel consumption. This occurs because it saves ". . . both the amount of fuel consumed while idling at stop and the extra fuel needed during accelerations after stops."

Claffey (*356*) presents the results of a series of tests conducted by him to measure the fuel consumption of an automobile under various situations. He used an 8-cylinder, 4,000-lb, 1964 American sedan with automatic transmission. He found that "the optimum speed for passenger car fuel economy on level, straight, high-type pavement is a steady 35 mph." At this speed, fuel consumption is 20.7 miles per gallon. He found that at a steady 80 mph the test vehicle achieved only 13.4 miles per gallon and at a steady 8 mph it achieved only 10.9 miles per gallon.

The results of the tests made by Claffey relating fuel consumption to speed emphasize an important problem concerning highway improvement projects. If such a project causes an increase in speed above 35 mph, it will cause fuel consumption to increase. This increase in speed will, however, produce time savings. Thus, there exists a trade-off between these two types of user costs. There exist many other trade-offs as well in the highway field. Thus, the analyst cannot really be certain that an improvement that reduces a few elements of cost will actually be the "best" improvement to make. It could be that other costs are increased so much that they far outweigh the savings produced by the given improvement. This example serves to emphasize that all the relevant costs and benefits should be taken into account in any benefit-cost study. If only those elements of cost that are reduced are examined, the analyst may conclude that a given improvement is "best" or acceptable when in fact it is not.

Tire Wear

Another element of operating cost is tire wear. The AASHO Report (*352*) lists type of surface, speed, grades, curvature, and the type of operation as factors that can influence tire wear. Tire wear increases with surface roughness, wear being less for paved than for gravel surfaces. Tire wear can also increase with increased speed. The AASHO Report says that, for example, the tire wear at a running speed of 53 mph was found to be three times the wear at 33 mph. Only approximate data are furnished for the effect of grades, but studies of tire wear seem to indicate that grades of up to 4 percent can be ignored. The type of operation can influence tire wear because of increased wear caused by stop-and-go driving.

Claffey (*355*) says: "Highway improvements that result in route shortening and/or improved surface conditions will save on tire cost while improvements that provide for higher operating speeds will increase tire cost." He goes on to say that the amount of tire wear is affected also by other conditions that can be changed by highway improvements. The factors that he mentions are ". . . number and steepness of grades, amount of curvature, and number of stop and go and slowdown operations required." He differs from the AASHO Report, which presents actual figures on tire wear, when he says: "The saving in tire wear per vehicle-mile which can be achieved through any one of these highway improvements is so small that no practical method is available for measuring it accurately."

Oil Consumption

Oil consumption is yet another element of operating costs, frequently mentioned in the literature, that can be reduced through highway improvements. Data relating oil consumption to various design elements of the highway are rather scarce, however. The AASHO Report (*352*) mentions grade, alignment, operating conditions, speed of travel, and surface type as factors that may affect oil consumption, but states: "While it is likely that changes in grade, alignment, and operating conditions also affect oil consumption, no data are available to show definitely that these are of sufficient importance for consideration. Therefore, the speed of travel and surface type are the major factors considered to affect oil consumption." That report states a belief that oil consumption increases with speed and increases with the roughness of the surface. Claffey (*355*), however, believes that there are so many factors to take into consideration when measuring the effects of highway improvement on oil consumption that distance reduction is the only improvement that need be considered.

Maintenance and Repairs

Another element of the cost of vehicle operation is the cost of maintenance and repairs. The AASHO Report (*352*) states: "It is difficult to establish a relation between the conditions of vehicle operation and the expenditures for maintenance or repairs." This occurs because of the various degrees of maintenance attention given the vehicles on the road. The report says: "Tests have been made on several types of surface, the results of which support the conclusion that costs of maintenance are least on the high-type surfaces. While it seems logical to conclude that high speeds, steep grades, or poor alignment might also tend to increase maintenance costs, information is not available to demonstrate such a conclusion." Claffey (*355*) concludes that maintenance costs can be reduced ". . . through highway improvements which reduce route length. In addition, the cost of some items . . . will be reduced through improvement of road surface and improvements which reduce number of stop and go and slowdown operations." He says, though, there is limited information in the literature on this subject.

Ownership Costs

Vehicle ownership costs are other elements of the cost of operation frequently mentioned in the literature. The AASHO Report (*352*) says that they include garage rent, taxes, licenses, insurance, interest, and time depreciation. These costs are constant throughout the year regardless of vehicle use. The report says: "At first consideration it would seem that there are no benefits related to these items since the total cost is constant." It cites studies that show that, except for the wealthy, ". . . there is a definite relation between motor vehicle expenditures and income. Thus when a highway improvement reduces the cost of passenger car operation it is logical to conclude that many vehicles will be driven a greater distance. Since this increased use is obtained without any increase in total ownership cost, there is a service benefit to the individual road user." It goes on to say that if the increase in use is included in the expanded traffic volume for the analysis, ". . . the benefits determined for the higher traffic volumes may well include the benefits the individuals receive by reason of the increased service." Thus, this may involve a substantial amount of double counting. The AASHO Report does not differentiate the benefits that may accrue because of ownership costs. In the analysis it is assumed that these benefits are included through the procedure of estimation of future traffic volumes.

In the foregoing discussion of vehicle ownership costs, time depreciation was mentioned as one of the components. This type of depreciation is independent of the vehicle use and is only a function of age. Another type of depreciation is that which is related to vehicle use. There is not much agreement in the literature as to all the factors that affect depreciation due to use, nor is there much agreement as to the percentages of total depreciation that should be attributed to time and use depreciation, respectively. Some analysts argue that ". . . depreciation cost is almost entirely unaffected by use. Others suggest that about one-half of vehicle depreciation cost is due to miles of travel accumulated by a vehicle, arguing that if a vehicle were not operated at all, its depreciation cost would be about 50 percent of what it is after being used" (*356*). Other authors argue that depreciation of passenger cars ". . . is partially due to vehicle use, not as measured by miles of travel but as measured by such matters as frequency of stop-and-go operations, frequency of persons entering or leaving the vehicle by sliding over the seats, and the type of service performed by the vehicle" (*356*).

The data on depreciation as related to vehicle use are rather scarce. There has been no definite assignment of differences in depreciation as related to type of highway. The AASHO Report (*352*) says: "While lower-type surfaces may cause greater wear, this is partially compensated for by the lower speeds and perhaps fewer miles of daily use. Then, too, the greater wear on lower-type surfaces already has been given weight by greater charges for maintenance." It goes on to say that no other factor seems to be related directly to depreciation and assumes depreciation to be $0.0150 per vehicle-mile for all types and classes of highways. Claffey (*355*) agrees with the AASHO Report when he says: "The depreciation cost of a properly maintained passenger car can be reduced through road surface improvements, but the amount of such benefit is small and practically impossible to evaluate. The benefits passenger car users achieve through reduction of depreciation cost through highway improvement can be neglected."

Time Savings

Another benefit frequently mentioned in the literature that may accrue to road users is a reduction in travel time. Although it is no easy task in itself to measure the time savings in minutes or hours, there exists a much more conceptually difficult problem associated with time savings. This is the placing of some dollar value on the savings. For the purpose of placing value on time savings, vehicles are usually divided into passenger cars and commercial vehicles. Separate values of time are calculated for each class of vehicle. Some authors also have tried to estimate the value of travel time to commuting motorists. When only one type of vehicle is being considered, the value of time varies with the purpose of use. Thus, the value of time for commuting motorists may differ from the value of time for leisure driving.

There is general agreement throughout the literature that some value can be placed on the travel time of commercial vehicles, although there is not much agreement as to what that value should be. On the other hand, when private automobiles are considered there is not much agreement as to whether this type of savings should even be considered as a benefit, let alone as to what the value should be. Mohring and Harwitz (*350*) say that some highway planners do not take time savings of private automobiles into consideration as a benefit because ". . . many of these beneficiaries use their time savings in leisure activity and the view that leisure, being 'unproductive,' has no value."

Mohring and Harwitz take issue with this line of reasoning. They state: "Such a view considerably distorts the goals of economic activity." They argue that ". . . most people work not primarily for such pleasure as work may itself provide, but rather because the money rewards entailed enable them to buy goods and services desired in their own rights." They go on to say: "Most self-employed individuals could sacrifice leisure for other goods and services by working longer hours. Similarly, many salary or wage earners who work fixed hours could increase their dollar incomes by holding more than one job. That they choose not to do so or, indeed, not to spend all of their waking hours working, reflects the fact that they place a lower value on the financial rewards of additional work than on the pleasures of some leisure hours." They conclude that ". . . the uneasiness of highway planners about crediting highway improvements with dollar benefits reflecting private passenger vehicle occupant time savings is totally unwarranted."

There are various ways that the analyst may go about placing a value on time savings. The revenue and the cost savings methods are two means frequently mentioned in the literature to value the time savings of commercial vehicles. The willingness-to-pay method is a way frequently used to value the time savings of private automobiles. Finally, there is the cost-of-time method, which is used not to value time savings, but to ascertain the cost of providing these savings. Each of these methods is discussed in turn.

Revenue Method

The revenue method, also referred to as the net operating profit method, is a technique used only to value the time savings of commercial vehicles. It is assumed that time savings will permit an increase in the revenue-miles driven by the commercial vehicle, as the vehicle will be driven more miles in the same amount of time. Because the hours of operation will be the same as before the time savings, the costs of operation that vary with hours of operation will remain fixed. Thus, for every hour of time saved by highway improvement, the owner of the commercial vehicle is permitted one additional hour of revenue operation at no additional cost of those factors that vary with hours of operation. Adkins, Ward, and McFarland (*351*) say: "The net operating profit method of determining a value of time is based on the premise that time savings are used to operate additional revenue-miles at a reduced average cost per mile. The value of time saved is taken as the additional net revenue which the time savings will permit. It is assumed that the increase in output of transportation services increases over a range in which marginal revenue and marginal variable expenses are constant. Certain vehicle and labor expenses, which are variable with hours of operation, are assumed to remain fixed as increased miles are operated in the time saved."

Cost Savings Method

The cost savings method is also used for the evaluation of commercial vehicle time savings. Whereas the revenue method assumes that time savings are manifested as an increase in revenue-miles in the same amount of time, the cost savings method assumes that time savings will permit the same amount of mileage to be driven as before, but with the use of fewer resources. Thus, according to the cost savings method, time savings will be manifested through the use of fewer vehicles and drivers to do the same amount of work as before. The costs that are reduced are those costs that vary with hours of operation, or those associated with the reduction in the number of drivers and vehicles. These costs include interest, depreciation, and property tax on the equipment that is reduced, and wages, welfare, workman's compensation, and social security (payments by the employer) for the released drivers.

As was mentioned, one item of expense that is assumed to be reduced by the cost savings method is interest. Adkins, Ward, and McFarland (*351*) say: "To the extent that equipment requirements are reduced with time savings, interest on investment can be saved." They go on to say: "Interest is a time charge and will be diminished if the investment on hand at any given time is reduced." Thus, ". . . less interest will be paid (implicitly, of course) if the basic assumption of the cost savings model holds; that is, that fewer vehicles and fewer drivers will be required to perform a given quantity of transportation."

The use of interest charges in the cost savings model is open to dispute. As mentioned previously, if one of the goals of the highway agency is to promote social welfare, and if the promotion of social welfare by the highway agency can be obtained through an expansion of the productive capacity of the economy, interest charges should not be used as a cost to society that is "saved" by highway improvement. Highway improvements are beneficial to society when they permit the expansion of the productive capacity of the economy through the use of fewer resources to obtain the same level of output or through the expansion of output with the use of the same level of resources. The cost to society in resources used to obtain a given level of output is not money cost, but the cost in real goods and services whose consumption society must forego to obtain the given level of output. Money is only a means of measuring how many resources society must use to attain some stated level of output. Interest charges as a money cost do not use up any of society's resources. They are merely a transfer of income from highway users or highway intensive goods users to bondholders. To repeat, they do not constitute a using up of resources, and as such should not be treated as a cost to society. Interest charges are, however, a problem in the computation of highway benefits and costs, but their reduction should in no way be included as a benefit for society.

Another factor included in the cost savings model that is assumed to be reduced is depreciation. As mentioned previously, depreciation is related to many factors. It was also noted that there is not much agreement as to which factors affect depreciation, nor is there much agreement as to what percentage of total depreciation can be attributed to each factor. Adkins, Ward, and McFarland (*351*) say: "The framework of the present problem requires that depreciation be assigned either to vehicle-miles or to hours of operation. One basic assumption of the study of time savings value is that the saving in time will result in a smaller number of vehicles. Remaining vehicles will attain the same total mileage and more miles per vehicle. But the fewer vehicles will accrue less obsolescence (a calendar time factor) and will be subject to less total weathering and less time-associated deterioration." In their study, they include all depreciation as a component of the model. They say: "This appears to pre-empt depreciation from assignment as a mileage factor. It is suggested, however, that the final proportions assigned to hours of use and mileage should rest upon experience and future research findings."

Another cost that is assumed reduced in the cost savings model is the cost that accrues to the owners of commercial vehicles through property taxes. Adkins, Ward, and McFarland (*351*) say: "Personal property taxes are a general revenue source and are ad valorem in nature. Less highway equipment via time savings will reduce taxable value and lead to reduced property taxes. At the same time, it may be argued, the over-all tax base will be reduced. Thus, the tax burden on the eliminated vehicles might be shifted to other properties, including retained equipment, given a static framework. In view of the extremely small proportion that taxable highway equipment comprises of the total tax base, this possible shifting may be ignored. Savings in property taxes through time savings thus appear to be in harmony with the basic 'fewer resources' assumption in the model."

The inclusion of property taxes in the model can be attacked on the same grounds that interest charges were attacked. That is, property taxes do not constitute a using up of real resources, and as such their reduction should not be calculated as a benefit for highway improvement.

Another item of expense that the cost savings model assumes is reduced is drivers' wages. There exists much doubt concerning the inclusion of this item of expense due to lags. Adkins, Ward, and McFarland (*351*) mention that some drivers in for-hire carriage are paid on a mileage basis. They say that, in the short run, a time saving may not lead to a saving in drivers' wages. Most drivers in private carriage are paid on an hourly basis, but they note that there still may be some lag in a reduction of this item of expense. They go on to say: "The incidence of the benefits may not be solely upon employers. Some benefits may accrue to drivers through increased leisure and may be considered social gains."

They also mention that if a reduction in all of drivers' wages are included as benefit due to a savings in time, there is none left to attribute to a reduction in mileage. This is fine if time savings never occur because of a reduction in mileage. "But it is known that time savings often occur because road mileage between two points is shortened. The question arises as to whether or not a time saving without a mileage decrease would bring the same reduction in drivers' wages cost as a time saving and a mileage saving occurring together. In view of the link between hours and miles in wage determination, at least in the short run . . . it seems likely that a combination of time and mileage savings would yield the greater amount of savings of drivers' wages." They say that a similar question arises when ". . . time is saved at the expense of greater miles of travel. . . ." Driver wage savings would be less in this case than if mileage were the same.

Drivers' nonwage savings are associated with a reduction in drivers' wages. Adkins, Ward, and McFarland mention that a reduction in these costs may not be the same for private carriage as for common carriage.

Willingness-to-Pay Method

There are several willingness-to-pay methods used to value time savings. All the techniques, however, involve the same basic methodology. They differ only with regard to the type of situations being compared. The essence of the method requires the calculation of opportunity costs to estimate how much of other goods and services, at market prices, motorists are willing to forego to obtain one hour of time savings. This opportunity cost is then the estimated value of time savings. Adkins, Ward, and McFarland (*351*) say: "Willingness-to-pay methods to derive a value of time savings are applied to situations in which individuals are faced with a decision of choosing between time savings and other benefits (or values). That is, there exist situations in which the individual can save time, but such time savings are accompanied by increased (or opportunity) costs. It is postulated that the individual will make that choice which best fits his pattern of preference, including the evaluation of his time. In any specific calculation, the proportion of drivers making a particular decision between alternatives would be studied."

Three willingness-to-pay methods are presented by these authors, as follows:

1. Alternate-route-of-travel method.
2. Alternate-mode-of-transportation method.
3. Alternate-speed-of-travel method.

Each method is discussed in turn. It is worth mentioning that the willingness-to-pay methods are used primarily to evaluate the time savings of private automobile drivers.

In the alternate-route-of-travel method, the analyst must find situations in which the motorists are given a choice of different routes of travel. Adkins, Ward, and McFarland (*351*) say that the analyst must find situations in which:

1. "The user is aware of available alternatives.
2. "He is informed about the differentials in operating costs, accident rates, time of travel, and strain and inconvenience afforded by the alternative routes.
3. "He makes a rational decision between the alternatives.
4. "The alternate routes have a common origin and destination, in the opinion of the highway user."

They mention two situations where alternative routes were available and were used in previous studies, as follows:

1. "One route saves time, the alternate route saves user cost.
2. "One route saves time and/or has user costs and accident savings but has a toll charge, and the alternate route has no toll charge."

These same authors say that the alternate-mode-of-transportation method ". . . analyzes situations in which people have the choice of using different modes of transportation with different travel times and costs." They go on to say that the difference in costs is some "minimum" value that the faster transportation users place on time savings. A knowledge of ". . . the percentage of persons using the faster transport and their distribution of values of time . . ." is necessary to calculate a full willingness-to-pay value of time.

The third willingness-to-pay method discussed is the alternate-speed-of-travel method. This method seeks situations in which the motorist makes a decision to travel at higher speeds ". . . with a resulting higher cost per mile of operation" (*351*). As discussed previously, there exists some optimum speed at which operating costs per mile are minimized. As the driver increases speed, these per-mile costs also increase. "It is postulated that the increased cost from operating speeds higher than the optimum are a measure of the driver's willingness to pay for the time saved by operating at the higher speed" (*351*). Adkins, Ward, and McFarland (*351*) mention the following assumptions that underlie this method:

1. "The driver must be rational in his decision making.
2. "The driver must have information about the cost per mile of operating at different speeds.
3. "The driver must be free to drive at the speed which he considers appropriate to his preference pattern."

There is much doubt as to whether these assumptions are a reasonable representation of reality. Adkins, Ward, and McFarland (*351*) state: "Many drivers may not be aware of the operating costs per mile at different speeds." They also mention that there is a tendency for drivers to "move with the traffic." Also, there are mechanical and legal limitations to how fast a motorist may drive. Some motorists may also enjoy driving at high speeds. Others may place a disutility on a situation that requires them to drive faster than some accustomed speed.

Cost-of-Time Method

The cost-of-time method differs from the other methods discussed previously because, instead of calculating the value of time savings itself, this method seeks to compare alternative highway projects according to the cost of providing the savings. Adkins, Ward, and McFarland (*351*) say: "The cost-of-time method differs substantially from other methods in that it is project-oriented rather than user-oriented. Values of time are derived by determining the cost of providing time savings for alternate road designs and for alternate routes of construction. Such cost-of-time values are designed to rank roads in order of their desirability."

Haney (*364*) discusses the cost-of-time method in detail. He says: "Although a single willingness to pay might be used to evaluate all projects of a certain class, the costs of specific projects may differ. Each project will have its own cost of time." He defines the cost of time as ". . . the actual cost of providing time savings on a specific project," and gives the following definitions:

$R =$ the benefit-cost ratio;
$V =$ the value of time, in dollars per passenger car-hour;
$\Delta t =$ savings in annual travel time, in passenger car-hours $(t_0 - t_1)$;
$\Delta u =$ savings in annual user costs $(u_0 - u_1)$; and
$\Delta h =$ the increase in annual highway costs $(h_1 - h_0)$.

Then let the cost of time,

$$C = (\Delta h - \Delta u)/\Delta t \qquad \text{(E-7)}$$

with $(\Delta h - \Delta u)$ considered as the ". . . net change in annual transportation costs." Thus, Eq. E-7 indicates how much it costs in dollars for a given alternative highway project to provide one hour of time savings.

Haney introduces the benefit-cost ratio, R, which is only a slight variation of the benefit-cost ratio used in the highway field, mentioned earlier. So, let

$$R = (V\,\Delta t + \Delta u)/\Delta h \qquad \text{(E-8)}$$

A project will just break even if $R = 1$, from which it follows that

$$R = 1\left(\frac{V\Delta t + \Delta u}{\Delta h}\right)$$

$$V = (\Delta h - \Delta u)/\Delta t \qquad \text{(E-9)}$$

or

$$V = C \qquad \text{(E-10)}$$

That is, with a benefit-cost ratio of 1, the value of time is equal to the cost of providing that time savings.

Haney notes that in most situations, the benefit-cost ratios will not be equal to one. Most alternative highway projects will have benefit-cost ratios in excess of one. So, if $R > 1$, Eq. 8 becomes

$$R = \frac{V\,\Delta t + \Delta u}{\Delta h} > 1 = (V\,\Delta t + \Delta u)/\Delta h > 1 \qquad \text{(E-11)}$$

and

$$V > (\Delta h - \Delta u)/\Delta t \qquad \text{(E-12)}$$

but

$$C = (\Delta h - \Delta u)/\Delta t \qquad \text{(E-7)}$$

hence

$$V > C \qquad \text{(E-13)}$$

Haney says: "Thus with a benefit-cost ratio greater than 1.0, the estimates, in effect, indicate that the highway user would actually be paying somewhat less for time savings than the estimated value that he is willing to pay." It should be noted that throughout his analysis, Haney assumes that $\Delta h > 0$ and $\Delta t > 0$. That is, he assumes that highway costs and time savings are always positive.

Haney also says that little confidence can be placed in the willingness-to-pay value of time. He proposes a method of analysis to evaluate alternative highway projects in which all factors except the willingness to pay must be known, using the cost of providing time savings. He says: "If the calculation of the economic worth of a particular project were made in terms of the cost of time, it appears that significantly increased insight could be gained as to the importance of this factor, and that project priority lists could be prepared which do not depend so heavily on a willingness-to-pay value of time on which little confidence can be placed."

Consider the four highway locations given in Table E-9. In this example, taken directly from Haney (*364*), it is assumed that either three or four alternative projects are being considered at each of four locations. The estimates in the table are in dollars, hours in tens of thousands; Δh stands for the increase in annual highway costs, in dollars; Δu designates the savings in annual user costs for each alternative, also in dollars; the minus sign indicates an increase in user costs; Δt indicates the savings in annual travel time that accrue from a given alternative project, in passenger car-hours.

Haney assumes that the total budget for the highway agency is \$11.7 million. Based on a 7 percent rate of interest and a 20-year analysis period, he says that the equivalent annual capital cost of this budget is \$1.1 million. The analysis is carried out using the \$1.1 million figure.

As mentioned previously, Haney says that little confidence can be placed in the willingness-to-pay value of time, and that estimates of this value of time range from \$1.00 per hour up to \$2.00 per hour. But the ranking of alternatives can be very sensitive to the assumed value of time. If little confidence can be placed in the estimate of the value of time, little confidence can be placed in the ranking of alternatives using this value. By use of incremental benefit-cost ratios, Haney shows how the ranking of the alternative projects in this example can change for different assumed values of time (Table E-10).

In this example, the ranking of alternatives is indeed very sensitive to the assumed value of the willingness to pay. Haney proposes choosing the various alternatives by the cost of time instead. This method permits a ranking of the alternatives that is not so dependent on the assumed value of time.

As discussed previously, the cost of time given by Haney is defined by Eq. E-7 .What must be done is to order the alternatives by increasing highway costs. Incremental costs of time are then computed using the same procedure as the incremental benefit-cost ratio technique when there exists a fixed budget and various alternatives under consideration at more than one location. The only difference between the use of incremental costs of time and incremental benefit-cost ratios as the criterion of choice is that the alternatives are compared according to their incremental cost of time.

For example, if at location 1, alternative 2 is compared with alternative 1, the incremental cost of time is computed as $\dfrac{(\Delta h_2 - \Delta h_1) - (\Delta u_2 - \Delta u_1)}{(\Delta t_2 - \Delta t_1)}$. Thus, the incremental cost of time for alternative 2 as compared to alternative 1

$$= \frac{(70{,}000 - 20{,}000) - [-20{,}000 - (-10{,}000)] \text{ dollars}}{(140{,}000 - 110{,}000) \text{ hours}}$$

$$= \frac{60{,}000 \text{ dollars}}{30{,}000 \text{ hours}} = \$2/\text{hour}.$$

The incremental procedure is continued until the "best" set of projects is determined under the budget constraint.

The best set of projects as determined by the incremental cost of time is:

LOCATION	PROJECT
1	4
2	1
3	2
4	2

It should be noted that the choice of projects using the incremental cost of time is the same set chosen with an assumed willingness to pay of $1.00 per hour. Upon comparison of the two procedures to rank alternatives, Haney (*364*) says that the set chosen by the cost-of-time method ". . . provides significantly lower average cost of time than those selected using $1.50 per hr and $2.00 per hr in a benefit-cost ratio procedure."

He goes on to say: "The set derived using a willingness to pay of $1.50 per hour would result in greater time savings than the set chosen by the cost of time, but to attain these additional time savings the incremental cost of time would be about $1.21 per hour. If this incremental cost of $1.21 could be justified on the basis of the willingness to pay, the $1.50 set should be accomplished. But it has already been admitted [in this example] that the value of time may be as low as $1.00 per hr; therefore, it is not possible to state with confidence that the willingness to pay is at least $1.21." Haney goes on to say that this is a good illustration ". . . that the willingness to pay cannot be completely ignored, and it also indicates the economic advantage of choosing projects by the cost-of-time procedure."

Cost of Accidents

Another road user cost that can be reduced by highway improvement is the cost of accidents. The analyst faces two rather difficult problems when he attempts to use the cost of accidents in his analysis of highway improvement projects. The first problem involves the extreme difficulty in obtaining any statistically significant estimates of how much a given highway project will affect accident rates. The second problem involves attaching some dollar estimates to the cost of accidents. The latter problem is taken up in this appendix.

The usual method of placing a value on the cost of accidents involves enumeration of all costs associated with various types of accidents. The costs usually enumerated are the so-called "direct" costs of a given type of accident. These direct costs are then estimated for the various accidents that occur in the geographical area that the analyst studies during a given time period. Some average value is then formulated for the costs of each type of accident. It should be noted, however, that there is not much agreement in the literature as to which elements of accident costs are to be included as direct costs.

Most studies of accident costs classify accidents by severity. Thus, the usual estimates of the costs of accidents are presented as the cost of:

1. Property-damage-only accidents.
2. Nonfatal injury accidents.
3. Fatal accidents.

One problem faced by the analyst who wishes to place some dollar estimates on the cost of accidents occurs when two or more vehicles are involved in an accident. If, say, a fatal injury occurs in one vehicle, should the other vehicles be classified as being involved in a fatal injury accident even though there were no fatalities in them? Smith (*371*) presents the results of a study of accident costs in the Washington, D.C., metropolitan area from April 1964 to March 1965. This report says: "All vehicle involvements were classified according to the severity of the accident rather than the severity applicable to each vehicle involved. Thus, a vehicle might have been involved in a fatal injury accident, and might have been classified as a 'fatal injury involvement,' even though no one was injured in this particular vehicle and little or no cost was incurred."

TABLE E-9

INCREMENTS OF COSTS AND TIME SAVINGS FOR ALTERNATIVE HIGHWAY PROJECTS

LOCATION	ALTERNATIVE	Δh	Δu	Δt
1	1	2	−1	11
	2	7	−2	14
	3	15	7	20
	4	23	17	19
2	1	26	2	53
	2	47	3	77
	3	95	3	92
	4	120	8	99
3	1	21	37	5
	2	35	28	33
	3	62	1	61
4	1	11	16	26
	2	21	−5	81
	3	38	−45	122

TABLE E-10

PREFERRED ALTERNATIVES AT DIFFERENT VALUES OF TIME

LOCATION	WILLINGNESS TO PAY $1.00/HR	WILLINGNESS TO PAY $1.50/HR	WILLINGNESS TO PAY $2.00/HR
1	4	2	2
2	1	2	1
3	2	2	2
4	2	2	3

The Washington study, like many other studies of motor vehicle accident costs, presents the data in terms of vehicle involvements rather than accidents. If a traffic accident occurs, and two vehicles are involved, there are two involvements scored. Thus, to change data from a per involvement basis to a per accident basis, all that is needed is to know the average number of vehicles involved per accident. Simple multiplication of the average number of vehicles per accident by the per involvement cost yields the per accident cost.

Elements of Direct Costs

As stated earlier, most studies of the costs of accidents measure only direct costs. After these costs are enumerated, the analyst measuring accident costs computes the costs that have occurred for each accident to be studied. Some average value is then computed, and this value is the average direct cost of accidents for each severity class. The elements of direct cost for the Washington study (*371*) are as follows:

Property Damage Costs:

1. "Damage to or loss of the case vehicle itself (including any road repair or tow charges).
2. "Damage to property in the vehicle (including luggage and personal effects exclusive of an injured person's clothing).
3. "Damage to property outside the vehicle, but not another vehicle (such as utility poles, signs, hydrants, fences, hedges).
4. "Miscellaneous costs usually incurred because the accident occurred away from home (such as transportation, accommodations, and telephone calls, but excluding ambulance costs or hospitalization).
5. "Rental fees, exclusive of operating costs, of replacement vehicles or, for trucks, the net income lost because the vehicle was out of service.
6. "Rental income lost through unavailability of the car or truck (for vehicle rental or leasing agencies only).
7. "Value of work time lost by owner and/or driver.
8. "Value of work time lost by persons other than owner or driver.
9. "Fees paid to lawyers, but only that portion relating to the property damage aspect of the involvement.
10. "Surplus damages awarded, the amount by which damages collected from a third party exceeded the total of all other costs."

Personal Injury Costs:

1. "Cost of ambulance service, prorated according to the number of persons served.
2. "Transportation costs related to medical treatment.
3. "Costs of professional services of doctors, surgeons, and dentists.
4. "Costs of private nursing services, in the home or hospital, not included in the hospital bill.
5. "Hospital charges for all services, drugs, etc.
6. "Costs of drugs, supplies, eyeglasses, braces, and special equipment such as wheelchair or crutches, not included in doctor fees or hospital bill.
7. "Miscellaneous costs, such as replacing damaged clothing, convalescing away from home, and related items not covered elsewhere.
8. "Funeral costs.
9. "Value (gross earnings) of work time lost by the injured party.
10. "Value of work time lost by persons other than an injured party taking leave from their employment to care for the injured party or look after his interests.
11. "Costs of additional or substitute domestic or household services.
12. "Fees paid to legal advisors representing an injured person or a survivor, exclusive of legal costs of an insurance company.
13. "Surplus damages; i.e., the amount by which damages actually collected from a third party exceeded the total of all other costs incurred because of personal injury.
14. "Present value if the loss of future earnings by those fatally injured, and by those with a permanent impairment, either total or partial."

The Washington study differs from most studies of accident costs in that it includes funeral expenses and the loss of future earnings in the elements of direct costs. Indirect costs are not measured in this study. The report says that indirect costs are: "Expenditures of money which resulted from the accident problem as a whole but which could not be related directly to specific or individual accident occurrences. . . ." It goes on to say that included in indirect costs are ". . . proportionate expenditures for traffic enforcement activities of the police; motor vehicle administration, including driver licensing, driver education, and safety responsibility laws; overhead costs of collision, comprehensive, and personal liability insurance; highway improvements through design and operation; traffic engineering treatments; and other accident prevention activities."

As stated earlier, there is not much agreement in the literature as to all of the components of the direct costs of accidents. Smith and Tamburri (*370*) discuss several accident cost studies, among them a study of the costs of accidents in Illinois (*383*). They say that these costs are so-called "out-of-pocket costs" and include the money value of:

1. Damage of property.
2. Ambulance use.
3. Hospital and treatment services.
4. Doctor and dentist services.
5. Loss of use of vehicle.
6. Value of work time lost.
7. Legal and court fees.
8. Damage awards and settlements.
9. Other miscellaneous items.

but not the money value of:

1. Loss of future earnings except for damage awards or settlements in or out of court for such items.
2. Expenditures by public or private agencies for accident prevention.

3. Expenditures by public or private agencies to mitigate the economic burden of accidents.
4. Overhead cost of insurance.
5. Funeral costs.

The direct and indirect costs of accidents, however the analyst may define them, are sometimes lumped together and called the economic cost of accidents inasmuch as they involve the expenditure of money. These same authors then define the noneconomic costs of accidents as those losses that do not involve an expenditure of money on the part of society or the victim of the accident. The noneconomic costs are also called the intangible costs of accidents. Little (*349*) presents a slightly different view of the economic and noneconomic losses of accidents, saying that the economic losses are ". . . the losses of net output of goods and services due to property damage, personal injury, and death." The noneconomic losses, according to Little consist of two parts: "The first part is the pain, fear, and suffering of the victims due to death or personal injury. The second part is the loss of consumption on the part of the victim and family." It should be noted that no one has yet found an acceptable way to value or even quantify the noneconomic costs of accidents, except for the second part of this type of loss as defined by Little.

Little also discusses some of the elements of economic cost: ". . . insurance payments in excess of costs should not be included in economic costs," as they may include some compensation for loss of earning power, but they may also include a payment for pain and suffering. It should be recalled that one of the goals of highway improvements is to expand the productive capacity of the economy. Insurance payments, however, represent only a transfer of income and do not of themselves contribute to an expansion or contraction of the productive capacity of the economy. Little says: "In no case does an insurance payment per se represent a social cost, since it is a transfer payment which has little effect on the resources available to society." The report says, however, that the overhead cost of insurance should be considered as an economic cost, as: "The proper measure for cost is the marginal cost of insurance overhead, or the amount total cost is reduced when the accident rate declines." Neither the Washington study (*371*) nor the Illinois study (*383*) includes the overhead cost of insurance as an element of direct cost.

Both the Washington study and the Illinois study include damage awards as part of the direct cost of accidents. Little (*349*) takes issue with the placing of this item in the direct cost category, saying: "Damage awards should not be included as part of the economic costs of accidents, for they represent transfers of income and no direct loss. Although they may represent in part the valuation of pain and suffering, and other social costs, they are a very poor and imperfect measure of such losses. They may, if desired, be considered when the noneconomic losses from accidents are considered. They should not, however, be included as part of the direct economic cost."

One element of the cost of accidents included as an element of direct costs in the Washington study but not included in the Illinois study is the cost of a funeral for those victims fatally injured. The Washington study includes the full cost of a funeral as an element of direct cost and estimates its cost at around $1,000. Smith and Tamburri (*370*) say that funeral costs should not be considered as an element of direct cost ". . . as it is reasoned that death is inevitable, and that an accident merely fixes the time of death."

Little (*349*) points out, however, that ". . . the relevant cost is the difference between a payment of funeral expenses at the present and the present value of funeral expenses discounted over the expected number of remaining years of life had the victim not been killed in the accident. . . . Since roughly half of all motor vehicle victims are under thirty-five and since few victims are otherwise close to natural death at the time of the accident, the error introduced by including funeral expenses directly is much smaller (for any reasonable interest rate) than that introduced by excluding these expenses altogether."

Another element of the costs of accidents included in the Washington study as a direct cost but not included in the Illinois study is the loss of future earnings of fatally injured and permanently impaired victims. The procedure used to calculate this loss in the Washington study ". . . required that the potential earnings of the deceased person be considered had he or she enjoyed a normal work life, as well as any reduction in long-term earning capabilities of injured persons. Anticipated earnings were based on Bureau of the Census data obtained from special tabulations prepared for the District of Columbia. Estimated 1964 wage and salary data which related to education, race, and sex classification of employed persons were utilized." What was done, then, in the Washington study to calculate the loss in future earnings was to first estimate the income that the victim would have received had he or she enjoyed a normal work life. The loss in future earnings was computed for every victim included in the sample. Because future incomes differ for different individuals, the Washington study took the following factors into consideration when estimating this cost for each victim:

Fatally Injured Person:
1. Age.
2. Sex.
3. Race.
4. Employment status.
5. Level of education.
6. Remaining years of expected life.

Permanently Impaired Person:
1. Age.
2. Sex.
3. Race.
4. Employment status.
5. Level of education.
6. Extent of impairment, total or partial (percent).
7. Effect on earnings of permanent-partial impairment.
8. Reduction in potential earnings.
9. Estimate of disability, if not in labor force.

Thus a white male with a college degree will have a certain expected income, a nonwhite female without a degree will have another, and so on. All of the foregoing factors were considered when estimating the expected future earnings of the victims.

After the factors that influence the expected future earnings of the victim of an accident were considered, the next step in the analysis by the Washington study involved the determination of how many years of life to assume the victim would have remained productive. That is, an assumption must be made as to how long the "work-life span" of the victims lasts. The Washington study chose for the work-life span of males the ages of 18 to 65, and that of females the ages of 18 to 62. The report states: "The procedure of limiting the work-life span of males to age 65 and females to age 62 did not imply that individuals were no longer productive after reaching the specified age limits. Some men could be gainfully employed throughout their lifetime; others would retire from one type of employment and then be engaged in another, on either a part-time or a full-time basis; and still others could be engaged in productive work around the home. Most women, of course, would continue their work in the household. The decision to limit work-life to 65 for males and 62 for females was considered to be a realistic compromise. . . . If the deceased person's age was 65 or over (males) or 62 (females), no loss of future earnings was calculated even though the person was gainfully employed at the time of death."

The estimation of the work-life span for women in the Washington study presented some difficult problems. For example, "Labor force participation of women was influenced by a number of factors, the principal one being marital status. Child-rearing and economic considerations of the family contributed to the practice of married women moving in and out of the labor force" (*371*). A study is cited that seems to indicate that women have a substantially shorter labor force participation period than men. Therefore, "In selecting the work-life span for women ages 18 to 62 it was recognized that this might be an overstatement of actual employment."

Another problem faced by the Washington study in the estimation of the loss of future earnings was the occupational status of the housewife. The study attempted to place on these services some numerical value without the benefit of market prices and also the determination of the work-life span of housewives. The report cites a University of Michigan study that assumed the cut-off period for this type of employment to be age 75, or the same as the average life expectancy. However, the Washington study assumes the work span for this activity to be 18 to 62, which is the same as that for employed females, and further assumes that the earnings assigned to this occupation be one-half those of employed males; that is, $3,978 per year for white females and $2,302 per year for nonwhite females. The level of education of the housewife was not considered. Thus, the assumed annual earnings for this occupation remained the same for all levels of education.

There are, of course, a few arguments that can be made against the method of the evaluation of housewives' services as presented in the Washington study. To begin with, the assumption that the value of housewives' services be one half that of employed males was made without any justification whatsoever, either theoretical or empirical. The only hint of justification was that a previous study (*384*) ". . . selected the figure of $3,000 per year as the value of a housewife's work. . . ."

When evaluating housewives' services at one-half that of employed males, the Washington study implicitly makes the assumption that a housewife contributes precisely one-half as much to the net output of the economy as does her husband. Such an assumption is purely arbitrary and limits the value of this study.

This method of evaluating housewives' services makes a distinction between the value of white and nonwhite services, the latter having the smaller value because employed nonwhite males tend, on the average, to have smaller incomes than employed white males. Levels of education are not considered when computing the value of housewives' services. Although the latter method does lend itself to theoretical justification (i.e., that no matter how educated a woman is, the duties she performs as a housewife are largely the same and should be valued at the same level), the former method may lead to erroneous conclusions. For example, a fairly good argument might be made for nonwhite housewives' services being valued above that of white housewives. (Because nonwhite families on the average tend to have more children, more work may be performed in the caring and rearing of their children.)

Prest and Turvey (*301*) suggest a different approach to the evaluation of housewives' services. It is suggested that the opportunity cost of being a housewife be estimated; that is, her income if she were otherwise employed. The argument is that this represents a minimum estimate of what these services are worth to the family. Still another approach would be to estimate the cost of a replacement. This is not the cost to the husband of seeking another wife, but rather the cost of hiring a housekeeper.

The next step in the analysis of the losses of future earnings in the Washington study (*371*) was to estimate maintenance costs for the victims of accidents. The loss in future earnings for fatally injured persons except for males over 65 and females over 62 ". . . was offset to the extent of subsistence costs of the individual had he or she lived the expected life span. Subsistence or maintenance costs were set at $2,000 per year for persons age 11 and older, and $1,000 per year for the first 10 years of life." It should be noted that the subtraction of future maintenance costs is a logical step in the calculation of the losses of future earnings. If, as stated earlier, one of the goals of highway improvements is to expand the productive capacity of the economy, maintenance costs should be subtracted from the expected future earnings. It is reasoned that, because the maintenance costs are a "using up" of real resources on the part of the individuals being considered in the analysis, the saving of these persons' lives does not constitute an expansion of the productive capacity of the economy by the amount of the maintenance costs. That is, to arrive at an individual's contribution to net output, maintenance costs should be subtracted from the expected future earnings.

Of course, the expected value of future earnings is not the important factor to be considered. What is important is the present value of expected net future earnings. Thus, to calculate the present value of net future earnings in the Washington study, the annual income of the deceased was taken from the Census Report. Income levels were broken down by age, sex, level of education, and race. The total expected income for this person until the cut-off age was then calculated. The present value of these earnings was then calculated using a 4 percent interest rate, as was the present value of future maintenance costs using the same interest rate. Subtraction of the two gave the present value of net future earnings. This was the value used in estimating the cost of a fatal injury accident.

The results of the Washington study (*371*) and the Illinois study (*383*) for passenger car accidents are as follows:

ACCIDENT TYPE	COST PER ACCIDENT ($) WASH., D.C.	ILLINOIS
Fatal injury	$47,481	$5,242
Nonfatal injury	863	821
Prop. damage only	193	100
All severities	527	196

These costs are on a per involvement basis and measure only direct costs as defined in each study. As can be seen, the two studies come close only in the nonfatal category. Little (*349*) says that the main reason for the difference in costs in the property-damage-only category is that the Washington study data applied only to reported accidents, whereas the Illinois data applied to all accidents, both reported and unreported. The major reason for the difference in the fatal injury class of accidents is that the Illinois study did not include the loss in future earnings as an element of direct cost. This element of loss is the single most important item of expense in the Washington study.

Little (*349*) takes issue with the Washington study for discounting the expected future earnings at a rate of 4 percent, saying that this rate is too low. They took the Washington data and used two discount rates on it, 4 and 10 percent ". . . representing a low and high value" (*349*). As stated earlier, Little (*349*) also disagrees on the use of damage awards and the presentation of the full amount of funeral expenses in the analysis; therefore, the Washington data were adjusted ". . . by deducting the excess damage costs, crudely modifying the present value of funeral costs, and adjusting the present value of lost net future income when a 10 percent discount rate is assumed." The adjusted costs are as follows:

ACCIDENT TYPE	4 PERCENT	10 PERCENT
Fatal injury	$47,000	$26,300
Nonfatal injury	770	740
Prop. damage only	193	193

The foregoing discussion was designed to indicate how the analyst attempts to place some value on the costs of accidents. It should be recalled that the costs discussed are only direct costs, however the analyst may define them. The purpose of such an analysis of accident costs is to attach some minimum value on the loss that will be felt by society because of motor vehicle accidents.

Some authors, however, take issue with the placing of dollar values on the costs of accidents. Kuhn (*365*) says that he is ". . . personally perturbed by the persistent attempts to put dollar values on highway fatalities and injuries." He says: "It does not really suffice to characterize this sort of approach as undesirable 'boneyard economics.' It has nothing whatsoever to do with economics; there is no market for human life, health and grief, and there will never be one, it is hoped. For professionals in the transportation field themselves to translate human life into dollars and cents is not only highly misleading, it may even be regarded as amoral by some." He says that this should not distract from the information on accidents per se, and suggests that the analyst present the accident data to the decision maker without the use of prices. He does believe, however, that property damage accidents can be presented to the decision maker in dollars and cents ". . . because acceptable market values for property exist."

Intangible Costs

Earlier in this appendix the noneconomic losses due to accidents were briefly discussed. It should be recalled that some authors divide the costs of accidents into economic and noneconomic costs. The former involve losses that have direct dollar values; the latter involve losses of things for which no market exists. It should also be recalled that Little (*349*) says that noneconomic loss consists of two parts: (1) the pain, fear, and suffering of the victims, and (2) the loss of consumption on the part of the victim and his family. They also say that the economic losses are the losses to society of net output of goods and services due to accidents.

Little (*349*) stresses that the economic costs of accidents are the minimum that society will lose from an accident. "Since the economic costs to society are relatively concrete compared to the losses of the victim, there is a tendency to use these as policy parameters. This leads to certain discomforting results, such as that old people are a net burden to society. The correct interpretation of economic costs is that they are the lower bound on the amount society would spend to prevent accidents; it is certain that the actual figure is much higher."

Little provides a method to take the noneconomic or intangible costs of fatal accidents into consideration in an analysis of highway improvement projects. Because there is no way to place any sort of value on the intangible costs, it is suggested that the analyst carry these throughout the analysis as a parameter, V. If it is assumed that there are 1.2 fatalities per fatal accident, the intangible costs of a fatal accident can be given as $1.2V$. Upon changing the Washington data to a per accident basis from the per involvement basis, the direct economic costs of a fatal injury accident are given by Little as $71,400. Thus, the cost of an accident, both economic and noneconomic, is given as $\$71{,}400 + 1.2V$. This does not include the indirect costs as defined in the Washington study. The analyst may carry this parameter through the evaluation of a proposed highway project and may obtain a result such as: Net benefit $= -\$59{,}900 + 0.190V$ [numbers taken from (*349*)]. This result can be solved to find what value must be assigned to V to make net benefit zero. In this example, Little says that the value of V is $550,000.

Another method mentioned in the literature to take the economic and noneconomic losses into consideration in an analysis of highway improvement projects is presented by Widerkehr (*373*), as follows:

$P_a =$ the fractional reduction in accidents attributed to a given highway safety improvement project;
$P_{fi} =$ the fractional reduction in fatalities and injuries combined for this project; and
$P_{pd} =$ the fractional reduction in the amount of property damage for this project.

Fatalities and injuries were taken together because ". . . the fatality sample sizes were too small for reliable estimates and, in many situations, fatalities are regarded as random occurrences among injuries so that apparent added severity of fatalities may not be a reliable indication of more severe roadway hazards."
Also, let

$$V = \frac{\text{Traffic volume after project was undertaken}}{\text{Traffic volume before project was undertaken}} \quad \text{(E-14)}$$

This factor is used "to readjust the fractional reductions in accidents to reflect projected changes in the traffic volume from the 'before' period to the period of analysis." The fractional reduction in accidents is multiplied by V to produce this readjustment.

To estimate the annual reduction in the number of accidents, the adjusted fractional reduction in accidents is multiplied by the annual number of accidents occurring during the "before" period.
Let:

$N_a =$ the annual number of accidents in the "before" period;
$N_{fi} =$ the annual number of fatality-injuries in the "before" period; and
$D =$ the annual amount of property damage in the "before" period, in dollars.

Thus:

$P_a N_a V =$ the annual reduction in the number of accidents by using a given project;
$P_{fi} N_{fi} V =$ the annual reduction in the number of fatality-injuries by using a given project; and
$P_{pd} D V =$ the annual reduction in property damage by using a given project.

Then let

$$Q = \frac{(\text{Cost of death}) + (I/F)\,(\text{Cost of nonfatal injury})}{1 + (I/F)} \quad \text{(E-15)}$$

in which (I/F) is the ratio between nonfatal injuries and fatalities. It is apparent that Q is the average cost of a fatality-injury since, if

$C_f =$ cost of a death, and
$C_I =$ cost of a nonfatal injury,

$$Q = \frac{C_F + (I/F)(C_I)}{1 + (I/F)}$$

$$= \frac{F\,C_F + I\,C_I}{F + I} \quad \text{(E-16)}$$

Thus, the total economic gain that accrues because a given highway improvement reduces accidents is

$$B_c = (Q\,P_{fi}\,N_{fi} + P_{pd}\,D)\;V \quad \text{(E-17)}$$

Widerkehr calls B_c the total calculable dollar benefit.

He also presents a means to estimate the intangible benefits that accrue because of a reduction of accidents. He argues: "If it is assumed that the loss to society attributable to all the intangible noneconomic factors for each accident is proportional to the calculable costs for the accident, then the intangible benefits are proportional to the calculable benefits." So, let R be the ratio of intangible benefits to calculable benefits (B_c); then RB_c represents the intangible benefits.

Now, let B be total benefits, both calculable and intangible, so that

$$B = B_c + R\,B_c = (1 + R)\;B_c \quad \text{(E-18)}$$

Therefore,

$$B = (Q\,P_{fi}\,N_{fi} + P_{pd}\,D)\;V\;(1 + R) \quad \text{(E-19)}$$

All that is needed is to find a value for R. Widerkehr states that R can never be measured directly, but a trial and error technique may suffice to estimate it. One way to estimate R is given by Jorgensen (*348*) who says that possibly a survey of the values of legal claims for losses attributable to the intangible costs of accidents may be a way to estimate it.

Strain and Discomfort of Nonuniform Driving

Another road user cost that can be reduced through highway improvement is the strain and discomfort of nonuniform driving. The AASHO Report (*352*) states: "There is value in the convenience of being able to go to one's destination without interference. There is a comfort value, over and above the saving in vehicle operating cost, in being able to drive without frequent brake applications, stops and starts, or unexpected interferences to travel. There is value in the conservation of health through driving in a relaxed manner without the tension necessary where roadside interference is imminent."

Many studies have shown that motorists are willing to pay for a reduction in this cost of operation. Furthermore, motorists are willing to give up time savings to attain a reduction in this cost. There are two problems involved in the evaluation of the strain and discomfort factor. One is the enumeration of the factors that affect strain and discomfort; the second, the placing of some dollar value on this cost.

Greenshields (*363*) proposes a method to measure the strain and discomfort factor on various roadways. His method entails calculation of the "quality of traffic flow," which is ". . . a function of the smoothness or lack of smoothness of flow. From the driver's standpoint it is a function of the lack of freedom of movement and is measured by his annoyance." Greenshields believes that not only is it slow speed that annoys the driver, but also the range and frequency of speed changes. He says: "It is reasonable to assume that the annoyance factor increases as the frequency and magnitude of speed changes increase." He says that small speed changes of 2 mph or less probably go unnoticed. Thus, the pertinent factors that affect the quality of flow are average speed, change of speed, and frequency of change and these three variables ". . . give a complete measure of the quality of flow."

Greenshields goes on to say that the quality of flow cannot be measured at a point, but must be measured over some distance: he chooses a mile. Thus, the three variables to be considered are:

1. Average speed, in miles per hour.
2. Change in speed per mile.
3. Number of changes in speed per mile.

Stopped time is not included in this analysis because: "Stopped time . . . is indirectly measured by the average speed, for a stopped vehicle is merely one traveling at zero speed. The more frequent the stops, the more frequent the changes of speed."

Greenshields defines the quality of traffic flow as

$$Q = \frac{K\,S}{\Delta_s\,\sqrt{f}} \tag{E-20}$$

in which

Q = the quality of flow;
S = average speed;
Δ_s = speed changes per mile greater than 2 mph;
f = the frequency of speed changes per mile greater than 2 mph; and
K = 1,000.

Eq. E-20 shows that as the average speed increases, the quality of flow increases; as the speed changes grow larger and/or the frequency of speed changes increases, the quality of flow decreases. Greenshields says: "Since small speed changes are not as annoying as large changes and since size of the changes decrease as the frequency increases, it is reasonable to decrease the weight given to larger frequencies." Thus, $\sqrt{f}$ is used in this formula rather than f. The constant 1,000 is included in the formula because the generated numbers are too small for convenience. The Greenshields formula yields a dimensionless number, Q, as a measure of the quality of traffic flow. It should be noted that the range of Q is from 0 to infinity. The lower limit represents a stationary state in which no traffic flows —a traffic jam. Q is infinite when the traffics flows at a constant speed, regardless of what that speed may be. These properties of Q make it a less than satisfactory measure of the quality of traffic flow.

Another interesting discussion of the strain and discomfort cost of nonuniform driving is presented by St. Clair and Lieder (*372*). They say: "Nearly all the factors that contribute to annoyance, discomfort, and nervous tension on a trip have their most direct and immediate effects in causing changes in speed (including reduction to zero speed). Sharp curves, steep grades, narrow roads, poor conditions of repair, left turns, right turns, STOP signs and signals, passing maneuvers and many other items cause the motorist repeatedly to check his speed, to accelerate, to stop, to start, or, in other words, to depart from the condition of uniform speed which is the characteristic of a pleasant trip. . . . Consideration of these facts led to the notion that the summation of speed changes on a trip might be used as a common denominator for the entire catalogue of impedances to uniform driving."

These same authors state, however, that experiments performed by Claffey seem to question the adequacy of the speed-change unit as an index of strain and discomfort ". . . largely because it fails to take account of the annoyance caused by forced driving at reduced speeds on 2-lane highways, occasioned by slow moving vehicles. There is also the case of prolonged stops, such as those at a red light, which involve a speed change at the beginning and at the end, but none during the duration." In light of this evidence, St. Clair and Lieder propose solving for the value of time and the cost of strain and discomfort using a method similar to the willingness-to-pay method of the evaluation of time savings.

EXTERNAL BENEFITS

Some authors make a distinction between internal and external benefits, the former being those that accrue to the users of the alternative projects being considered and the latter being those benefits to users of other facilities and benefits to nonusers. Kuhn (*365*), however, states that whether a cost or a benefit is external or internal depends on the viewpoint of the decision maker. He says: "Within the dichotomy of costs and gains, the distinction between internal and external values is made by defining the viewpoint, or planning horizon, or area of interest and responsibility, of the particular decision maker." He assumes that the objective of a transport agency is the promotion of public interest and that "Such public interest is whole and indivisible within the authority's geographic area of jurisdiction. . . . Therefore, all cost and gain effects set up by its actions will be internal to the agency's viewpoint and will be taken into account for decision-making."

Mohring and Harwitz (*350*) discuss a type of benefit that is seldom taken into consideration in an analysis of highway improvement projects. These are benefits that accrue to substitute facilities, thought of by some authors as external benefits. If a new roadway is built, traffic may be diverted from the older unimproved roads. There is sometimes a benefit to the users of the older facility that is usually not taken into consideration in an analysis. Mohring and Harwitz say: ". . . when the 'improved' highway is an entirely new facility, as is the case with much of the Interstate System, all of the traffic on it is either generated or diverted." Also, the diversion of traffic from the older to the newer facilities ". . . entails a reduction of the volume of traffic on these [older] routes. It, therefore, reduces congestion and increases the speed and comfort of traveling on them."

Benefits that accrue to nonusers are also considered by some authors as external benefits, and some even consider nonuser benefits and costs as the only type of external benefits. Thus, nonuser benefits are held synonymous with external benefits according to these authors. As stated earlier in this discussion, nonuser benefits can accrue in many ways: examples are (a) an increase in land values along a new roadway, (b) a decrease in the cost of transportation-intensive goods, and (c) an increase in the efficiency of delivery of transportation-intensive goods. These benefits also should be taken into account in any analysis of highway improvement projects.

There is an argument, however, that nonuser benefits are merely transferred user benefits. Thus, the inclusion of both user and nonuser benefits in an analysis results in a double counting of benefits. Zettle (*375*) says: ". . . it is my thesis that the benefits of highway improvement can be realized only as they are generated by highway use." We are guilty of multiple counting of benefits ". . . when we start to add up the benefits of highway improvement by looking alternately to the highway user, to the land owner, to the consumer, and so on until finally we come to the happy conclusion that everybody benefits from highway improvements." He goes on to state that highway users are the initial beneficiaries of highway improvement.

According to the argument presented by Zettle and other authors, benefits are usually substantially overstated when the analyst considers both user and nonuser benefits in his analysis. Thus, the relevant group of benefits to be considered in an analysis of highway improvements are the benefits that accrue to users.

This is not to say that nonuser benefits are no longer of any importance in a benefit-cost study. The incidence of both benefits and costs is an extremely important consideration in the analysis of highway improvement projects. Some highway improvements may benefit one group of individuals and cause loss to others. For example, if a new highway is built, land values in the vicinity of the new facility will rise. What is not considered in most analyses is that land values in another area may fall because of the new facility. This can occur to land along an older route that has traffic diverted from it to the new highway. Nevertheless, the increase or decrease in land values should not be considered either as a benefit or as a cost of a given highway improvement. It should, however, be taken into consideration in the analysis.

The literature in the highway field relating to nonuser benefits and the incidence of benefits is extremely poor. Crumlish (*357*) notes that "A review of the field indicates that the present practice among highway departments varies widely with respect to the extent of reliance upon economic analysis in decision making. There is a shocking gap in the literature when one looks for guidance in studying the economic and social consequences of expressways."

APPENDIX F

OVERDELINEATION—A FIELD STUDY OF THE SPEED/INTENSITY RELATIONSHIP *

Considerable controversy exists with respect to the optimum spacing/intensity relationships of various reflective devices. One form of argument taken by practicing engineers is that the reflective intensities, per se, on conventional delineators often encourage drivers to maintain average speeds in excess of "safe" speeds and that this occurs because drivers are lulled into believing that because they can detect a high-intensity post delineator at distances exceeding 4,000 ft they can "see" the road at this distance. A logical corollary of this point of view holds that speeds can be reduced by reducing the "offending" intensities. This "overdelineation" concept was subjected to empirical test in the field.

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PROCEDURE

A section of high-design four-lane roadway approximately 1.75 miles in length located in the Seven Mountains area of Route 322 (midway between Lewistown and State College, Pa.) was selected for use in the experiment. Figure F-1 shows the over-all geometry and the location of measurement points within the test section. A significant downgrade characterizes the entire test site. The downhill side was chosen so that desired speeds would not be influenced by power constraints.

Conventional radar units were used to obtain spot speed estimates at each of the three stations. Care was taken to ensure that the units were inspected and calibrated prior to each run, and that the same unit and observer were assigned to the same station for both the control and treatment

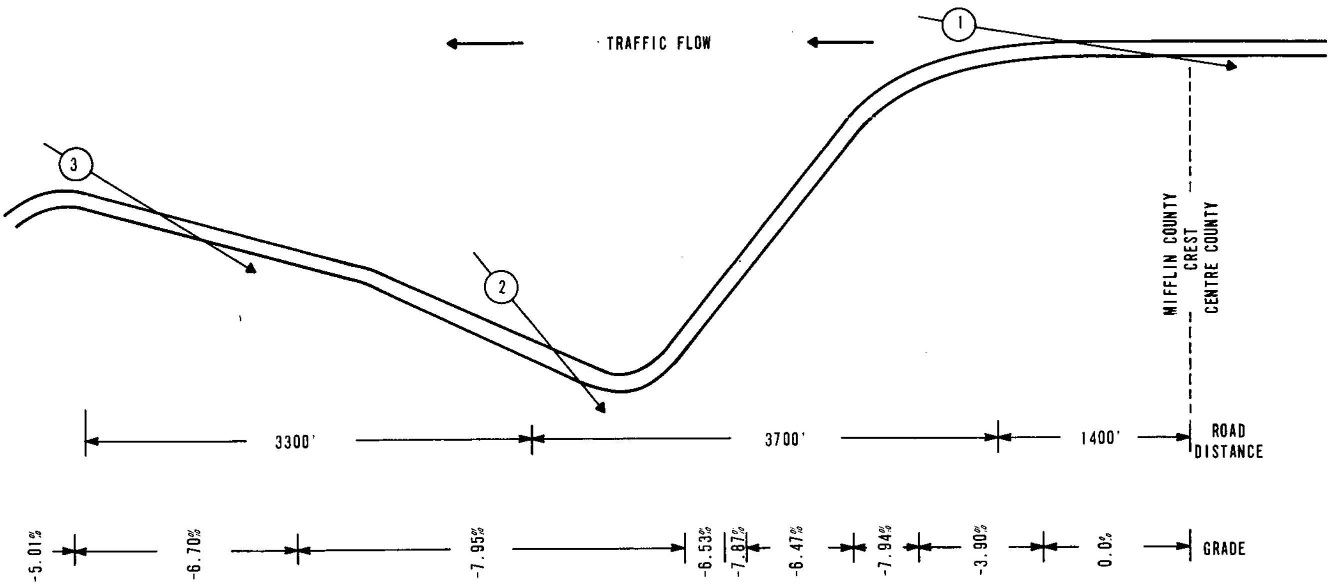

Figure F-1. Schematic of test section on US 322 in Seven Mountains area, Pennsylvania.

conditions (reference stakes and physical features were used to aim and align the antennas).

Observation periods were 2½ hr in length (9:30 PM to 12:00 M) on weekday nights. Vehicles were classified as passenger or commercial, and only free-flow vehicles were recorded; i.e., the headway between vehicles had to be sufficiently large to provide (despite the fairly acute angles produced by antenna alignment) for a zero (or null) reading on the meter between observations. The leader of a platoon was, however, accepted, because his view of the downstream delineation pattern was considered to be relatively unhampered.

The normal delineation for this section consists of formula-spaced clear post delineators on both shoulder and median (guardrail-mounted). In order to control the intensity of the clear post delineators as closely as possible, the reflective faces were washed clean prior to the experimental runs. Filters were installed on the median and shoulder post delineators to reduce the reflectivity to the level determined by a pilot study. As a standard for determining the density of the filters to be applied to the clear post-mounted reflectors, standard high- and low-intensity RPM's were evaluated. Seven filter densities ranging from 0.4 to 1.0 transmission density were judged in pair comparison tests against the RPM pair, and judges reported a highly favorable match on the relative intensity of the 0.7 transmission density filter. A diffuse transmission density of 0.7 translated to 20 percent transmittance. However, because in the retro-reflective situation the illumination is filtered twice (i.e., once going through the filter and once coming back), the total reduction in reflectance of the delineators is 40 percent.

On the basis of the pilot study 150 filters were prepared through controlled exposure and processing of black-and-white film. The reliability and quality of the reproduction process was continuously monitored and evaluated through the use of a densitometer. Black elastic harnesses were stapled to each filter, allowing for easy application and removal in the field.

The visual effect produced by the filtration process was significant, as shown in Figure F-2. To illustrate the difference in the reflectivity, filters were installed on every other delineator; the dramatic effect is shown in Figure F-3. Note that only three post delineators are visible on the shoulder.

RESULTS AND DISCUSSION

In general, the results tend to invalidate the "overdelineation" concept. The observed speed distributions that formed the basis for the comparison of the high- and low-intensity conditions are presented by vehicle type and location in Figure F-4. Associated sample means and standard deviations are summarized in Table F-1.

No statistically reliable differences were found in t-tests involving comparisons relevant to the intensity/speed relationship. One possible explanation for this is that the site, despite its initially appealing attributes, could have masked differences (i.e., the high-design limited-access situation could induce drivers to attend less to speed control because they have more room for forgivable error than they would, for example, on a rural two-lane highway). More likely, however, drivers use the advance warning as it was intended to be used and sample far information sparingly.

In short, there appears to be little hope for the regulation of speed through the manipulation of reflective intensities. Because the "effectiveness" of the post delineators shows no difference over a wide range of intensity, however, it might prove worthwhile to investigate the potential cost savings that could result from longer maintenance cycles.

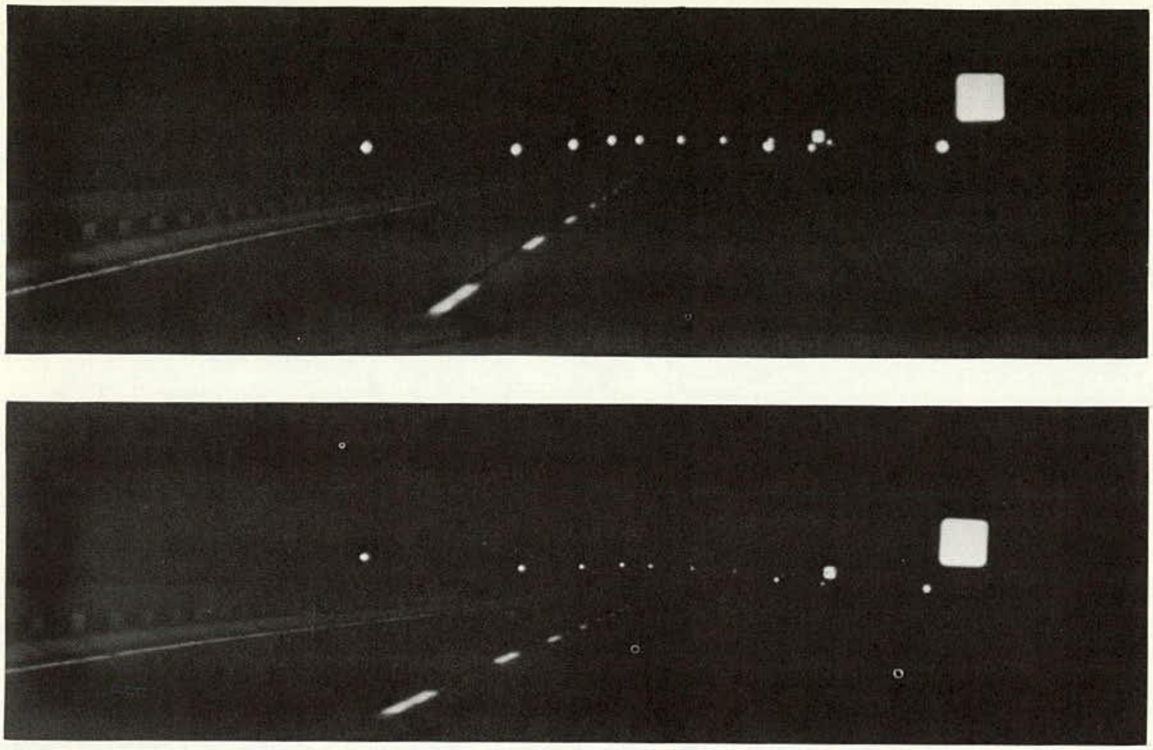

Figure F-2. Post delineator pattern on test section: (upper) conventional, high-intensity (unfiltered); (lower) experimental, low-intensity (filtered)

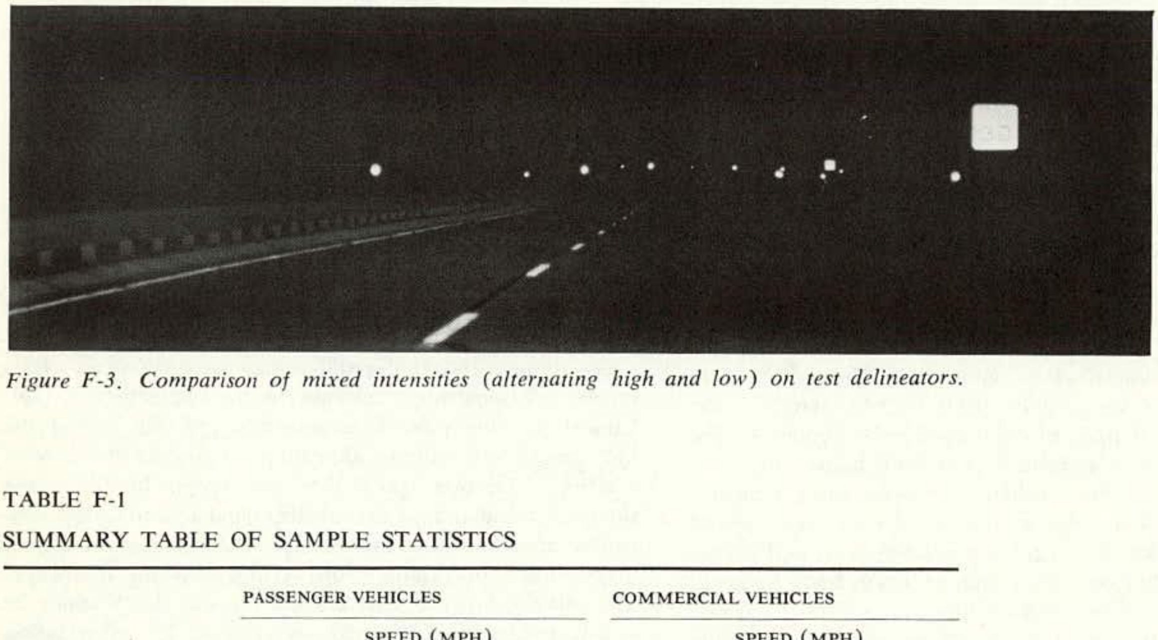

Figure F-3. Comparison of mixed intensities (alternating high and low) on test delineators.

TABLE F-1

SUMMARY TABLE OF SAMPLE STATISTICS

		PASSENGER VEHICLES			COMMERCIAL VEHICLES		
			SPEED (MPH)			SPEED (MPH)	
REFL. INTENSITY	LOCATION	NO.	MEAN	STD. DEV.	NO.	MEAN	STD. DEV.
High	1	270	46.73	8.64	85	34.46	8.27
	2	322	51.82	8.45	111	36.71	10.38
	3	328	53.06	7.53	125	42.83	9.51
Low	1	242	47.95	8.99	63	36.20	7.92
	2	266	52.20	8.75	58	38.12	9.96
	3	260	52.05	7.49	75	41.31	8.73

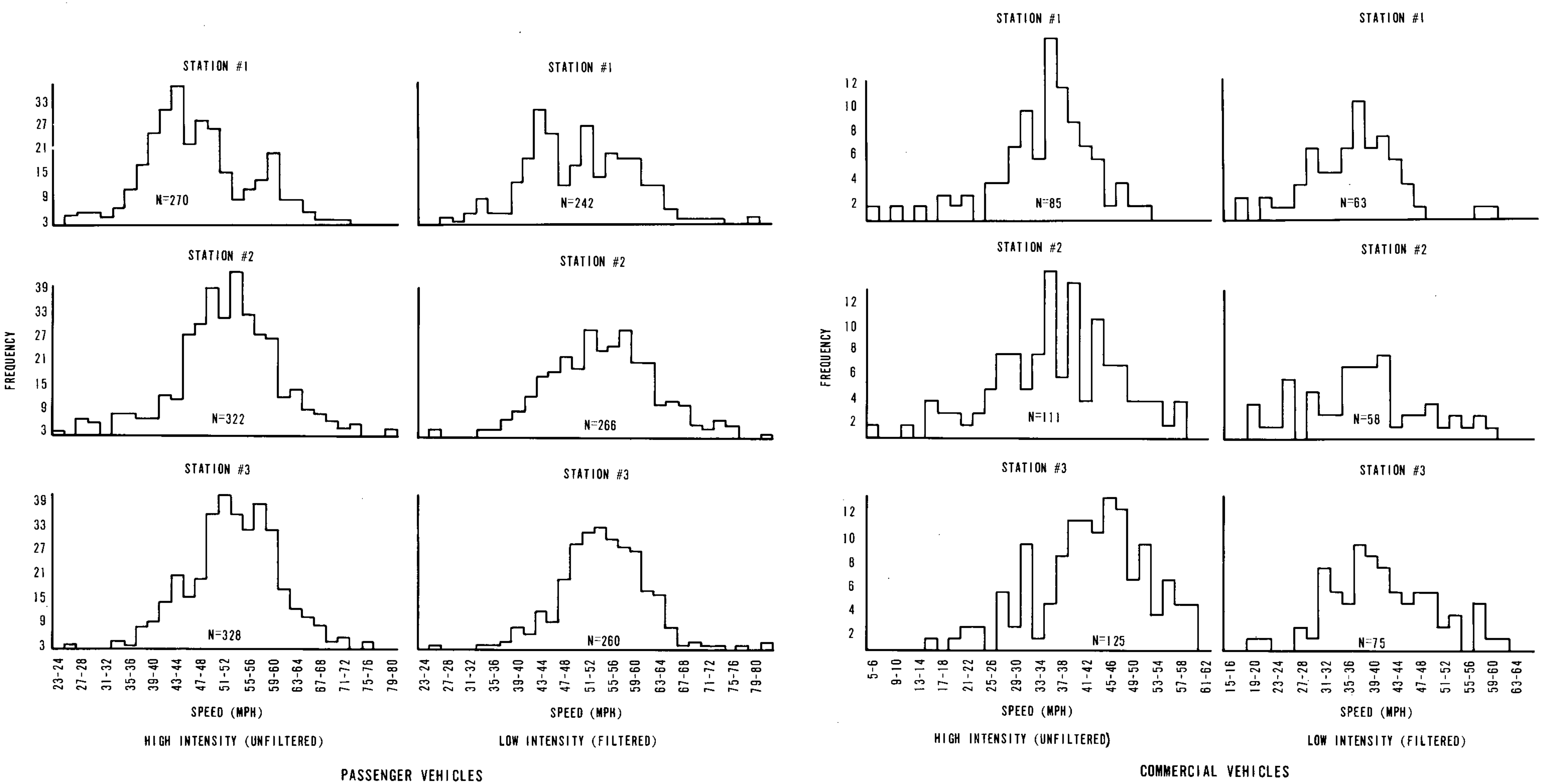

Figure F-4. Speed distributions of passenger and commercial vehicles on test section.

APPENDIX G

CODING AND INFORMATION VALUE STUDY *

In the early stages of this project it was decided that the performance of existing and promising new delineation codes should be assessed in terms of their relative effectiveness in discriminating between roadway situations. During the literature review and current practices survey several specific problem areas became apparent. Among the more important of these was that some of the codes currently in use produced a state of conflict for the driver. For example, in many cases amber post reflectors were used for exit ramps, curves, roadside obstructions, hazards and ditches, etc. Thus, a system that might otherwise be a reasonably good treatment would suffer from a lack of discriminability. Furthermore, the observed absence of standardization of practice both within and between states could only add to this problem. At this point it was decided to evaluate a few completely new codes in addition to promising ones that had been used on an experimental basis in the recent past.

The latter were included because they were judged from all rational standpoints of uniqueness, discriminability, etc., to be extremely promising. It was believed that perhaps the treatments or systems did not produce improved performance because drivers were not informed as to the meaning of the codes. Thus, the concept of driver information arose for consideration as a factor to be included in the study of codes. This, in turn, led to a consideration of the ways in which drivers assimilate delineation information. This learning can obviously occur through mass media public information efforts where the viewer or reader is informed as to the manner in which the various roadway delineation codes relate to geometric situations and potential maneuvering requirements.

The learning can also occur through successive exposures to the codes; i.e., where the driver perceives a stimulus (an unfamiliar code) and subsequently traverses the situation, and after repeated exposure makes the association between the two. In other words, the association is strengthened by feedback or knowledge of results. Also, it can be assumed that the more unique codes will be learned more readily than those that are used in a conflicting manner. However, there remains the problem of within and between state variation; i.e., where previous learning or associations may not help the driver. Thus, if the effect of information was to be assessed, it was decided that the baseline data should be from a group representative of drivers who had essentially no information about the relationship between codes and situations. It was hypothesized that drivers who were not informed about or had experience with code-situation associations would perform well only with codes/treatments that had high intrinsic informational value. However, drivers who were informed as to the code-situation relationships would do well both on codes with high intrinsic value and on those where uniqueness was high.

Another observation made during the current practices survey and in the search for on-the-road test sites was that in many cases the apparent effectiveness (or visual effectiveness) of a given treatment or system would vary considerably with the background and surroundings of the area in which it was used. In other words, either house lights and luminaires or other delineation in the background in some cases "cluttered" a curve, ramp, or stop approach to the degree that the situation was not immediately recognizable. It was also noticed that the more unique (or stronger) systems or treatments seemed more resistant to clutter. Therefore, it was decided to put this hypothesis to test in that the data would have practical implications (since clutter is a real-world problem). Also, resistance to clutter had potential for being a good measure of system strength.

An important factor in designing new systems is knowledge of the specific cues that drivers use to identify a situation. If, for example, both pattern and color cues are available, it would be interesting to know whether both cues or just one of the cues are noticed. Information of this kind about driver perception could help considerably in designing cost-effective systems; thus, it was decided to obtain data on specific cues in addition to the more general situation identification data.

All of these factors seemed to be interrelated to the degree that separate studies of code factors, information or education factors, clutter, and cue utilization were not reasonable, both from the standpoint of time and from the standpoint of acquiring enough individual subjects to have anything approaching matched groups. Thus, it was decided to collapse all of the factors into one large study using three groups of subjects for the information factors (i.e., no-information, information, and feedback groups) and duplicating the code and clutter factors for all three groups. To overcome the practical problems of scheduling and of time to run individual subjects, an electromechanical system was designed whereby the stimuli could be administered to groups of subjects while still maintaining rigorous control over experimental parameters such as the stimulus exposure and inter-stimulus intervals.

PURPOSE

The purpose of the study as finally designed was fourfold: (1) to assess the over-all effects of information and learning on situation identification; (2) to assess the relative effectiveness of selected codes, treatments, and systems for a number of situations; (3) to assess the resistance to

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environmental clutter of codes, treatments, and systems; and (4) to characterize specific cue utilization in terms of situation identification. Finally, in designing the study and choosing specific stimuli to be used, it became apparent that the system configurations to be assessed would also provide an evaluation of concepts that cut these problem areas; i.e., dual-reference (RPM's and posts) vs single-reference (posts or RPM's only) systems; color vs pattern, etc. All of the factors or concepts studied and the specific postulates tested are discussed in detail in the following sections.

METHOD

Part I. Situation Identification Procedure

The experimental procedure for all three experimental groups was designed to simulate the driving situation in which the driver previews the roadway ahead (on a sampling basis) in order to have knowledge of upcoming maneuvering requirements. The stimulus materials for the study consisted of slides of actual roadway scenes, some of which were first-generation photographs and some of which were manipulated in order to control (a) delineation and non-delineation cues (such as guardrails), and (2) background clutter of various types. These stimuli were presented with a conventional autofocus slide projector that was integrated into a system containing a large shutter and electronic activation and timing component so that exposure time and inter-trial interval could be accurately controlled. The apparatus and the preparation of stimuli are discussed in detail in later sections.

To simulate the glance recognition desirable in real-world driving, the subjects were shown each stimulus slide for a period of 1 sec. The subjects' task was to identify the situation shown. The answer sheet (shown in Appendix U) contained five alternative answers (situations) for each slide. Subjects were given 14 sec to scan the alternatives, check the answer, and look up at the screen for the next presentation. Pilot data showed the 14-sec interval to be adequate for responding. Subjects were instructed to select one best answer and leave no blanks. After each series of 20 stimuli, the subjects were given a 1-min rest period.

After the reading of instructions, each group was given five practice stimuli in order to familiarize them with the procedure. The subject instructions, both common and group specific, for each of the three groups were as shown in Figure G-1.

The information shown in Figure G-2 was provided to Group II in structured lecture form immediately before the test slides were presented. It was explained that some of the codes and treatments to be discussed were experimental and would not have been seen on highways. No attempt was made to be exhaustive with respect to MUTCD, current practice, or current experimental treatments. Questions were permitted after the information was provided. The time taken for presentation was approximately 15 min.

The Part I stimulus set included 120 slides that, with the interstimulus interval of 15 sec and the 1-min rest periods, consumed approximately 35 min. The representatives of each situation in the total 120 stimuli, including the pure and cluttered systems, are given in Table G-1. It will be noted that the 25 "clutter" slides had direct correlates in "pure" (uncluttered) systems. This was accomplished by using "pure" system slides and superimposing, photographically, random clutter patterns, holding the pattern constant within a situation type. This procedure permitted an adequate degree of control for the evaluation of resistance to clutter. A complete set of system specifications for each slide is given in Table G-2.

To have an unconfounded assessment of various systems for a given situation, it was necessary in some cases to use the same geometric configuration while varying the system. For this reason, it was necessary to use those slides listed as "dummies" in order to preclude a perception of sameness on the part of the subjects. The order of presentation and position of the correct answer among the alternatives was arranged randomly.

Part II. Cue Utilization Procedure

Part II of the study was accomplished during the same session as Part I, following a short break and the reading of Part II instructions (Fig. G-3). Part II required not only identification of the situation but also an indication of the color, treatment, and location of the cues recognized. The stimuli used for this session were selected from the set used for Part I and are indicated in Table G-2.

For this portion of the study, the stimulus exposure interval was kept at 1 sec, but the subjects were allowed 1 min to respond. The instructions were, again, to provide the one best answer on the situation identification portion. However, the subjects were told specifically *not* to guess in identifying cues they recognized. Up to three responses were allowed for each cue factor. As can be seen on the answer sheet shown in Appendix U, the subject was required to search the situation list and each cue factor list and select the numbers corresponding to his response(s) and record this number(s) in the appropriate blank(s). A different response alternative list was used for each set of five slides. With the exception of the situation identification list, which was always placed at the left edge, the positions of the cue lists and the order of the items within the list were randomized for each response sheet. A total of 25 stimuli and 5 different response sheets was used. The

TABLE G-1

SITUATION REPRESENTATION IN STIMULUS SET

SITUATION	NO. SLIDES
Ramp, pure	17
Ramp, clutter	7
Lane drop, pure	15
Lane drop, clutter	5
Stop approach, pure	12
Stop approach, clutter	5
Curve, pure	18
Curve, clutter	8
Distractors (dummies)	34

Common Instructions: Part I

The experiment you are about to participate in has been designed to help us better understand how the driver assimilates visual information. It has been designed as a laboratory study for several very good reasons:

First, it enables us to exercise some very important controls over variables which might, in an actual driving situation, produce unnecessarily complex and often uninterpretable data.

Second, the specific task that we are interested in is concerned with behavior that the driver engages in before he elects to modify his vehicle's movement.

Let's talk about the task for a moment. In traversing a roadway, a driver typically tries to maintain his vehicle at some personally desired speed within the bounds of (a) his lane of travel, and (b) the traffic in his immediate vicinity. Almost always, he has in mind a destination and so he must seek out information related to that destination. Drivers familiar with a particular area oftentimes use landmarks, while unfamiliar drivers tend to rely on signs, maps, etc. People in highway research have labeled this function "search and recognition." This search function involves more than seeking destinational information, however, because the driver is required to maintain his vehicle in a safe and efficient manner. In order to accomplish this, the driver tends to sample his environment visually. He notes, sometimes in fleeting glances, his lateral position relative to the shoulder, edge line, lane line, median divider, etc. He also tries to assess what is coming up; in other words, he previews the roadway ahead of him to determine what situation he will be in in the next few seconds. During the day, the preview could, under ideal conditions, provide usable information for the next full minute of travel at, say 60 mph. At night, however, in the same situation, the effective preview could be reduced to between 3 and 4 seconds, being limited primarily by headlamp coverage. You must realize though, that while the preview sampling provides information on what situation is in the immediate downstream area, the time taken for sampling itself often consumes only a fraction of a second.

Now we are at the point where I hope we can relate all of this to your task today.

In a few minutes, we will be presenting on the screen in the front of the room slides of roadway situations taken primarily at night. All we ask you to do is to identify each situation that you see in the preview fashion and record your answer on the answer sheet provided you. Now we get nasty. You will only have 15 seconds between slides so we ask your cooperation in being fairly fast about recording your responses. Another hooker: You will have only 1 second to view the screen, so immediately after you record your answer please direct your attention back to the center of the screen.

Now take a look at your practice sheet. Notice that for each slide presentation there are 5 alternative responses. Your job is to identify the situation shown in the preview slide and check the appropriate situation. Obviously, with the very brief presentation, some are going to be more difficult to identify than others. Please do your best at all times and do not fail to check one and only one situation for each slide that you see.

We have prepared some diagrammatic examples of what we mean by a "situation." Let's look at these for a moment.

[Present examples]

Most of these situations are familiar to you and our only purpose in presenting these slides at this time is to ensure a common terminology; i.e., what *we mean* when you see on your answer sheet something like entrance ramp, exit ramp, merge mainstream, diverge mainstream.

Now let's take a look at what you will be required to do. We will have a 5-slide practice session and then you may ask any questions you may have regarding the procedure. On the top half of your practice sheet you will see 5 sets of responses. Let's have a dry run. When you see the preview slide, identify the situation, select the best response, make your check mark, and prepare for the next slide. Everyone ready?—Begin.

[Present practice slides]

Are there any questions regarding the procedure?

If not (or after answering), please take a look at your answer sheet once again. Notice that we now ask for specific information regarding your driving experience and personal history. Please notice also that we do not wish you to identify yourself—unless, of course, you wish to. This study will in no way affect your grade for this or any other course.

Please take a couple of minutes now and answer these questions.

[Allow time to complete personal history info—Follow with specific group instructions]

Supplementary Instructions—No-Information Group (I)

Remember as you view these slides that the cues you get about what road situation is coming up stem not only from the geometry itself, but also often from other traffic and roadway delineation and markings. Please use all of the cues available to you to correctly identify the previewed situation. We know that this task may be a bit tiring and will at times be difficult. At the end of each page (after each set of 20 slides) we will have a one minute pause for you to stretch your neck and finger muscles. Is everyone ready?—Let's begin.

Supplementary Instructions—Feedback Group (III)

Remember as you view these slides that the cues you get about what road situation is coming up stem not only from the geometry itself, but often from other traffic and roadway delineation and markings. Please use all of the cues available to you to correctly identify the previewed situation. We know that this task may be a bit tiring and will at times be difficult. At the end of each page (after each set of 20 slides) we will have a one minute pause for you to stretch your neck and finger muscles. Is everyone ready?—Let's begin.

Following each slide and after a short delay during which you will record your response, the experimenter will inform you of the correct identification for the slide you have just seen. Please do *not* change your answer. It will render our results uninterpretable if you do, and it will gain you absolutely nothing. Remember, in no way will you be identifying yourself. So please cooperate with us and try to respond quickly so that the experimenter has time to tell you what the situation was before the next slide.

Supplementary Instructions—Information Group (II)

Remember as you view these slides that the cues you get about what road situation is coming up stem not only from the geometry itself, but often from other traffic and roadway delineation and markings. Please use all of the cues available to you to correctly identify the previewed situation. We know that this task may be a bit tiring and will at times be difficult. At the end of each page (after each set of 20 slides) we will have a one minute pause for you to stretch your neck and finger muscles. Is everyone ready?—Let's begin.

We will now spend a few minutes reviewing some of the delineation, (i.e., roadway markings, reflectors, color codes, etc.) that you normally find out on the roadways. In large part, these comments will be adapted from the *Manual on Uniform Traffic Control Devices,* but there will be some which are basically experimental. We want you to apply what you are about to learn to your task of identifying the situations previewed in the slide.

Figure G-1. Common and supplementary instructions to experiment subjects, Part I.

reason for the manipulation of list and item position was to prevent a bias from arising due to the typical scan pattern of subjects and to encourage a scan of all items.

Apparatus

To control stimulus exposure times and interstimulus intervals, and at the same time maintain the multiple-subject capability of the slide projector, an arrangement using a large shutter in conjunction with a conventional slide projector was devised. The shutter was mounted independently such that the projector could be moved for placement and focus adjustments and easily dismantled for traveling. The manual trip lever of the shutter was connected mechanically to a solenoid activated by a homemade power supply that yielded a 50-v starting surge and a 12-v constant potential. Completing the activation mechanism was a timer that provided fixed interstimulus intervals of 15 sec each. (A manual tripping switch was wired in bypass of the timer for use in Part II of the study.) Shutter speed was set prior to each session such that the stimulus was exposed for 1 sec. The timing was such that the exposure period occurred with a delay of 3 sec (after the slide had changed) so that the auto-focus feature had time to function. An electric timer was used to time the 1-min interstimulus intervals for Part II. The location used was a basement classroom with a built-in projection screen. The room was illuminated by a single 60-w bulb in an 8-in. reflector pointed at the ceiling. This arrangement provided

General

A. Information provided via delineation is coded in three ways: spatial arrangement (to indicate pattern of road); color; and location.

B. The colors used for coding are: white/clear; yellow/amber; green; red; purple; and blue.

C. The treatments used to provide information are: post-mounted reflective devices; raised pavement markers; paint striping; colored pavement arrows; and post-mounted shapes.

Situation Specific

A. Obstructions/hazards (drainage ditches, culverts, bridge piers, etc.):
   1. Yellow or white zebra striping (on roadway).
   2. Amber post reflectors.
   3. Black-and-white hazard markers.

B. Tangents:
   1. Two-lane two-way tangents:
      (a) Shoulder edge lines are white.
      (b) Center line may be white or yellow.
      (c) Passing zones will have broken white center line.
      (d) No-passing zones will have single solid white or double yellow center lines.
      (e) Clear post-mounted reflectors may be used on the right shoulder; these will be placed on 200-ft spacings.
   2. Divided-half tangents:
      (a) Shoulder edge lines are white.
      (b) Median edge lines are yellow.
      (c) Lane lines are broken white.
      (d) Clear post-mounted reflectors may be used on the right shoulder.

C. Curve:
   1. Right curve:
      (a) Amber post-mounted reflectors may be used on the left edge (outside of curve).
      (b) Clear post-mounted reflectors may be used on the right shoulder.
      (c) Amber reflective shapes indicating the direction of the curve may be mounted on posts on the left edge (outside of curve). [Note: Illustration of shape was drawn on blackboard]
   2. Left curve:
      (a) Clear post-mounted reflectors may be used on the right shoulder (outside of curve).
      (b) The amber shape discussed for the right curve may also be used for left curves; but in this case they would have the angle in the opposite direction and would be placed on the right edge (outside of curve).
      [Note: Illustration on blackboard used]
   3. Left and right curves:
      (a) The center line will be solid white or yellow paint.
      (b) A single or double line of raised pavement markers may be used for the center line.
      (c) Spacing of post-mounted reflectors is dependent upon curvature and they are placed closer together as the curve becomes more severe.

D. Ramp:
   1. Ramp proper:
      (a) Ramps may use blue post-mounted reflector and/or blue raised pavement markers on one or both sides.
      (b) Ramps may use amber post-mounted reflectors on one or both sides of the ramp.
   2. Gore:
      (a) White paint may be used in front of the gore. [Note: Illustration was used to differentiate physical gore from painted gore]
      (b) Clear raised pavement markers may be used in front of the gore, either with the paint or alone.
      (c) Blue or amber post-mounted reflectors may be used in the physical gore.

E. Stop approach:
   1. Red post-mounted reflectors may be used on the right edge of the approach area.
   2. Red raised pavement markers may be used on the center line of the approach area; may be used with or without the red posts.

F. Lane drop:
   1. Lane drops may use purple or amber post-mounted reflectors on the taper.
   2. Lane drops may use purple or amber raised pavement markers on the taper. [Note: Illustration used to indicate taper area]
   3. Amber reflective arrows mounted on posts may be used to indicate the direction of the taper. [Note: Illustration used to show post-mounted arrow]
   4. Yellow pavement arrows may be used to indicate the direction of the taper.

Figure G-2. Structured lecture outline for Group II (information group) information.

sufficient light to read and fill out response sheets without sacrificing the image quality of the stimulus slides. The projection distance was about 35 ft and the image size was approximately 4 by 6 ft.

Stimulus Preparation

Stimulus slides for final presentation were of four types:

A. Masters.*—Original slides with unwanted clutter (i.e., luminaires, house lights, etc.) removed.
B. Master derivatives.—Master slides with delineation elements removed or color changed.
C. Master supers.—Master derivative slides with deleted delineation replaced with experimental colors and/or placement.
D. Clutter slides.—Selected final slides from Groups A, B, and C with a situation specific clutter pattern added.

Each of the four types was prepared in a slightly different manner; therefore, each is explained in separate steps as required, with common or overlapping stages noted.

* The original slides from which masters were made were obtained from two sources: slides of real roadway situations and slides of treatments set up on a test site. One of the latter was a system of "shape posts," which consisted of two ½-in. strips of yellow high-intensity wide-angle reflective sheeting 10 in. long. One strip was mounted vertically on ¼-in. hardboard backing and the other intersected it at 45°, pointing in the direction of curvature of the road. These devices were mounted on 4-ft posts and were spaced as warranted for post delineators through a curve.

Subject Instructions: Part II

In this part of our experiment, we are not going to press you quite so much. You will still be getting the same brief exposure on slides that you have already seen; however, you will have a full minute to respond. Why are we so generous? Because this time in addition to identifying the preview situation, we would like you to spell out, as best as you can, what the cues were that you feel enable you to recognize the situation. If you will look now at the RESPONSE SHEET for Part II A, you will see that for each slide (numbered down the side) we would like you to identify from the lists above *up to* three of the cues that you may have detected. For example, you have three blanks under each list. On the slide that you have just seen, you may have noticed the colors red and yellow. You would then consult the color list and record in two of the three blanks *below* the *color list,* the numbers corresponding to *red* and *yellow.* The same procedure should be followed for the other lists except for the situation list, where you are limited to a single response. For the situation response, we would like you to give your *best* answer—please do not leave blanks. For the others, you may have either 1, 2, or 3 blanks, but please do not guess; rather, try hard to record the primary cues that you recognize and remember. Are there any questions? If not, let's begin.

Figure G-3. Subject instructions, Part II.

Type A—Masters

A-1. Original slides were photographed on internegative film using a Honeywell Pentax Spotmatic camera, a slide duplicator, and an electronic flash unit. In cases where the original photograph was shot in negative form, prints were made directly.

A-2. Color prints (3½ × 5 in.) were made at a commercial laboratory.

A-3. Unwanted surroundings and clutter were retouched out of the prints.

TABLE G-2

SLIDE DESCRIPTION IN ORDER OF PRESENTATION

Slide Number	Description	Slide Number	Description
1	SA 40/80 R rpm + #1 C posts + SS	71	Dummy
2	C(1) Clutter Correlate of #14	72	SA 40/80 R rpm #1 R posts + SS
3	LD(r) A pavement arrows + A posts	*73	R ramp-A posts outside; gore-split A/C rpm + split A/C posts
4	Dummy	74	SA 40/40 C rpm Conven. R posts + SS
5	LD(r) Clutter Correlate of #118	*75	R ramp-B posts outside; gore-B posts
*6	R ramp-A posts outside; gore-W paint only	76	C (r) Mixed A rpm CL C posts right
7	Dummy	77	Dummy
*8	C(1) No CL A posts right No left	78	C (1) Clutter Correlate of #69
9	R Clutter Correlate of #23	79	LD(r) Clutter Correlate of #53
10	Dummy	80	Dummy
11	Dummy	*81	LD(r) P posts
12	C (1) No CL No right C posts left	82	SA #1 R posts + SS
13	LD(1) A rpm	*83	SA Conven. R posts + SS
*14	C (1) No CL A posts right C posts left	*84	R ramp-B posts outside; gore-split B/C rpms + split B/C posts
15	Dummy	85	LD(1) A posts
*16	LD (r) A posts	86	LD(r) Clutter Correlate of #16
*17	R ramp-A posts outside; gore-A posts	87	Dummy
18	SA Clutter Correlate of #57	88	C (1) Single A post
19	SA 40/80 C rpm conv. C posts + SS	89	Dummy
20	Dummy	90	R Clutter Correlate of #73
*21	C (r) No CL No right A posts left	91	R ramp-B posts outside; gore-W paint
22	LD(r) A pave. arrows A shape arrows	*92	C (1) C posts right
*23	R ramp-A posts both sides; gore-W paint	93	Dummy
24	SA Clutter Correlate for #62	94	R ramp-A posts outside; gore-C rpm only
25	R ramp-A posts outside; gore-W paint + C rpm + A posts	95	SA 40/80 R rpm #1 R posts + SS
26	Dummy	96	Dummy
27	Dummy	97	C (1) Mixed rpm CL
28	C (1) No CL No right A shape posts left	98	LD(r) A pave. arrows P posts
29	C (r) No CL C posts right A posts left	*99	SA 40/80 R rpm #1 C posts
30	Dummy	100	Dummy
31	C (r) No CL C posts right C posts left	*101	LD(1) P posts
32	R Clutter Correlate of #84	102	LD(r) A pave. arrows A posts
33	R ramp-C posts both sides; gore-C rpm	103	SA 40/80 R rpms + SS
34	C (r) Clutter Correlate #63	104	Dummy
35	R ramp-A posts outside; gore-W paint + A/C split posts	105	Dummy
36	C (r) mixed A rpm CL	106	Dummy
37	LD(r) A posts + sign	107	Dummy
38	R Clutter Correlate of #112	108	R Clutter Correlate of #17
39	Dummy	109	R ramp-A posts both sides; gore-C rpms
*40	C (r) mixed A rpm CL No right A posts left	110	Dummy
41	C (r) Clutter Correlate of #21	111	Dummy
42	C (r) No CL C posts right No left	*112	R ramp-B posts both sides; gore-W paint
43	LD(r) Clutter Correlate of #81	113	Dummy
44	SA Clutter Correlate of #99	114	Dummy
45	R ramp-A posts outside; gore-W paint + A posts	115	C (r) Clutter Correlate of #40
46	Dummy	116	R ramp-C posts both sides; gore-W paint
47	Dummy	117	Dummy
48	Dummy	*118	LD(r) A rpm
49	R Clutter Correlate of #6	119	C (r) Clutter Correlate of #58
50	R Clutter Correlate of #75	120	Dummy
51	C (1) Clutter Correlate of #92		
52	Dummy		
*53	LD(r) C posts		
54	C (r) mixed A rpm CL No right No left		
55	SA Clutter Correlate of #83		
*56	SA No rpms Conven. R posts + SS		
*57	SA 40/80 R rpms No posts No SS		
*58	C (r) No CL No right C posts left		
59	Dummy		
60	R ramp-B posts both sides; gore-C rpms		
61	Dummy		
*62	SA No rpms Conven. C posts + SS		
*63	C (r) A shape posts left		
64	Dummy		
65	Dummy		
66	R ramp-B posts outside; gore-C rpm		
67	C (r) Mixed rpm CL C posts right A posts left		
68	C (1) Clutter Correlate of #8		
*69	C (1) C posts right C posts left		
70	Dummy		

*Appeared in Part 2

C - Curve (l) left & (r) right
LD - lane drop (l) left & (r) right
SA - stop approach
R - ramp
dummy - slide not used in analysis
W - white
C - clear
A - amber
R - red
B - blue
P - purple
CL - center line
post - post mounted reflective markers
rpm - raised pavement markers
-/- Split - Gore marking which is one color from the point into the ramp and a second color from the point through mainstream
pave. arrows - laid out with 3-M lane tape as per AASHO warrants for turn slot arrows

Mixed rpms - one retroreflective rpm for every four non-reflective ceramic rpms
40/80, 40/40 } rpm spacing (ft. from center to center) up to 700 ft/700 ft to stop sign
SS - Stop sign
shape arrows - described in stimulus preparation section
Conven. - conventional spacing for post delineators at a stop sign
#1 - a geometrically decreasing spacing for post delineators at a stop sign

A-4. The prints were then rephotographed to obtain the final slide form.

Type B—Master Derivatives

Steps A-1, A-2, and A-3 were accomplished before proceeding to the B-series steps, as follows:

B-1. The cleaned-up prints had certain delineation elements removed and others changed in color. The only color changes done at this stage were on existing delineation, which was clear where blue or amber were the colors needed.

B-2. These prints were then photographed to arrive at the master derivative slides.

Type C—Master Supers

All A- and B-series steps were accomplished before proceeding to the C-series steps, as follows:

C-1. "Punch-outs" were made by punching through the film of duplicates of master slides, making pin holes where delineators had been or where they were needed for the desired pattern. This slide was used as a template to make pinholes in blank slide covered with opaque metallic binding tape. When projected, this "punch-out" yielded a simulated pattern of delineation that could be filtered to any color and could be positioned in exact duplicate of the original delineation systems of parts of that system.

C-2. The punch-out slide was superimposed on a projection screen with a master derivative slide (B-2) to replace, supplement, change position of, or change color of the original delineation.

C-3. The combined image was then photographed using high-speed film for the final slide form of the master supers.

Type D—Clutter Slides

Finished stimulus slides (A-3, B-2, or C-3) were screened for needed code comparisons and certain of these were selected for clutter comparison.

D-1. Punch-outs for each of the four test situations were developed by subjective judgments by project personnel and manufactured in the manner described in C-1. The patterns were made up of from 6 to 12 holes (lights), depending on situations, and were arranged so that, in the opinion of project personnel, they were equally distracting for all patterns within each situation.

Opposite direction curve and lane-drop slides were made by reverse duplication of selected finished slides. For curves, slides were used that had been shot from the left side of the road, so that when they were reversed the view was from the correct lane. This process was not used for lane drops because the view was to be from the lane being dropped.

Subjects

The subjects used were both undergraduates and graduates in civil engineering at the Pennsylvania State University. They ranged from eighth-term undergraduates to second-year graduate students. Table G-3 gives descriptive data for each separate group and for the groups as a whole. All but one subject held a Pennylvania driver's license and 73 percent of the subjects had graduated from a driver education program.

RESULTS AND DISCUSSION

Because an ambitious number of objectives and a correspondingly high number of alternative hypotheses were involved in this study, it would be difficult and not too meaningful to attempt to characterize the results with general summary statements. Rather, for the sake of clarity in presentation, this section is subdivided on the basis of those objectives, and findings and generalizations are summarized accordingly.

It is necessary at this point, however, to introduce the over-all performance data for all groups across the slides. Table G-4 gives the percentage of correct responses for all slides. Three slides (39, 47, 80) were lost as far as analysis was concerned because of undetected errors in developing the response alternatives. Descriptive data, specifying (a) the type of slide (test, pure or clutter; or dummy); (b) situation; and (c) specific delineation configuration, are given in Table G-1. Taken together, Tables G-1 and G-4 form the basic data for all evaluations discussed, with the exception of the confusion index and the cue factor analysis (Part II). Data handling procedures for these evaluations are discussed in their respective sections.

An over-all impression of group differences not readily apparent in examining Table G-4 is obtained from the acquisition curves shown in Figure G-4. Each data point represents a mean percent correct for a block of ten slides plotted at the midpoint of its respective block. Figure G-4 appears to show sufficient strength in the observed trends to support the hypothesized group difference (viz., the initial undifferentiated identification performance and the subsequent emergence of an apparently reliable information effect); however, there must be acknowledged a design inadequacy that, unfortunately, denies use of Group III data. The order of presentation for all slides was determined randomly without constraints. Hindsight in examining these trends prompted recognition that the feedback procedure could have reinforced associations with clutter stimuli per se, because the clutter slide often appeared in the order prior to its "pure" system correlate. Although

TABLE G-3

DESCRIPTIVE DATA FOR SUBJECT GROUPS

GROUP	AGE (YR)	DRIVING EXPERIENCE: TIME (YR)	ANNUAL MILEAGE	URBAN DRIVING (%)	NIGHT DRIVING (%)
I	21.8	5.6	8278	46.3	33.6
II	21.5	5.8	6764	36.0	32.8
III	22.5	5.7	9769	43.0	37.0
All	21.9	5.7	8238	42.0	34.5

TABLE G-4

PERCENT CORRECT RESPONSE (SLIDE BY GROUP)

SLIDE NO.	PERCENT CORRECT: NO-INFO. GROUP I	PERCENT CORRECT: INFO. GROUP II	PERCENT CORRECT: GROUP III
1	22	64	31
2	6	21	17
3	22	29	39
4	89	100	92
5	39	64	46
6	50	79	69
7	50	64	77
8	44	43	23
9	83	100	85
10	83	50	54
11	11	0	8
12	18	7	23
13	56	50	77
14	44	29	58
15	18	21	33
16	18	36	69
17	22	14	31
18	11	43	39
19	22	57	23
20	17	7	54
21	22	36	46
22	39	79	31
23	83	93	92
24	11	7	46
25	61	36	85
26	53	79	77
27	28	14	15
28	83	79	46
29	6	43	46
30	67	57	85

SLIDE NO.	PERCENT CORRECT: NO-INFO. GROUP I	PERCENT CORRECT: INFO. GROUP II	PERCENT CORRECT: GROUP III
31	11	8	31
32	33	57	100
33	89	86	92
34	78	71	46
35	50	36	100
36	6	0	23
37	28	64	31
38	83	93	92
39[a]	—	—	—
40	72	71	75
41	47	43	77
42	56	57	31
43	22	21	77
44	28	64	62
45	89	100	100
46	33	29	46
47[a]	—	—	—
48	88	100	100
49	67	71	100
50	67	64	75
51	17	7	23
52	33	57	46
53	17	29	38
54	83	93	92
55	28	46	69
56	89	57	100
57	28	57	54
58	29	38	46
59	61	79	85
60	94	86	92

SLIDE NO.	PERCENT CORRECT: NO-INFO. GROUP I	PERCENT CORRECT: INFO. GROUP II	PERCENT CORRECT: GROUP III
61	44	50	31
62	11	7	77
63	100	100	85
64	39	36	46
65	28	21	25
66	72	21	100
67	78	79	92
68	47	43	54
69	53	36	62
70	0	0	7
71	39	57	69
72	50	86	85
73	33	57	100
74	28	64	92
75	72	36	54
76	89	79	92
77	33	43	31
78	29	14	85
79	11	43	46
80[a]	—	—	—
81	17	50	54
82	56	71	100
83	56	79	100
84	89	93	100
85	11	36	69
86	18	29	85
87	83	86	46
88	11	21	46
89	50	50	62
90	72	43	100

SLIDE NO.	PERCENT CORRECT: NO-INFO. GROUP I	PERCENT CORRECT: INFO. GROUP II	PERCENT CORRECT: GROUP III
91	83	79	100
92	24	57	69
93	94	100	100
94	94	86	100
95	56	86	85
96	22	29	38
97	0	7	15
98	29	29	62
99	50	57	92
100	11	7	38
101	28	50	62
102	22	50	77
103	56	93	100
104	67	64	77
105	22	14	46
106	61	71	85
107	33	50	31
108	83	64	77
109	67	57	100
110	72	36	67
111	89	71	100
112	61	43	100
113	33	43	23
114	11	7	0
115	89	86	85
116	61	57	100
117	11	14	50
118	44	64	100
119	24	36	46
120	83	50	77

[a] Scores unavailable.

patterns were random across situations, within-situation patterns were constant; thus, where the clutter-first condition occurred, the probability of a correct response as a function of the clutter pattern (as opposed to the delineation system) was enhanced. Further justification for removing Group III from comparative analysis stemmed from the fact that they were upper classmen who were then enrolled in a highway design course, whereas the other groups were sections of the same Introduction to Traffic Engineering course, typically reserved for underclassmen.

Although the latter limitation was apparent at the outset of data gathering, it happened that they were the only group available to round out the consideration of the manner in which drivers can obtain information. and so, with reservation, the group was accepted for study. No further apologies regarding the exclusion of Group III data are made; however, it should be emphasized that the information-dependent comparison is concerned with Group I vs Group II differences. In comparisons other than the information analysis, it was deemed appropriate to consider only within-group differences. In these instances Group I data were used, primarily because in its naievete concerning roadway delineation this group presents a more representative picture of the typical driver population. In any event, in the ensuing discussion the manner of handling the data for any comparison is made explicit.

One further comment is in order before leaving these group summary data, and that concerns the large performance decline shown in the 60-70 block for Groups II and III. Referring to Table G-2, it can be seen that an unexpected and, in fact, disproportionate number of dummy slides occurred in this block. A reasonable explanation for the dip in the Group II curve is that no code information was involved in the dummies; hence, there was no reason to expect a performance advantage over Group I. For the Group III dip, an equally plausible explanation exists in that regular feedback should show a rise in performance as a function of situation repetition; however, where dummy slides were concerned no such repetition was possible.

In the following sections, several types of analysis are presented for Part I data that are primarily in the form of frequencies (this includes proportions, and even probabilities). The chi-square (χ^2) statistic had been selected

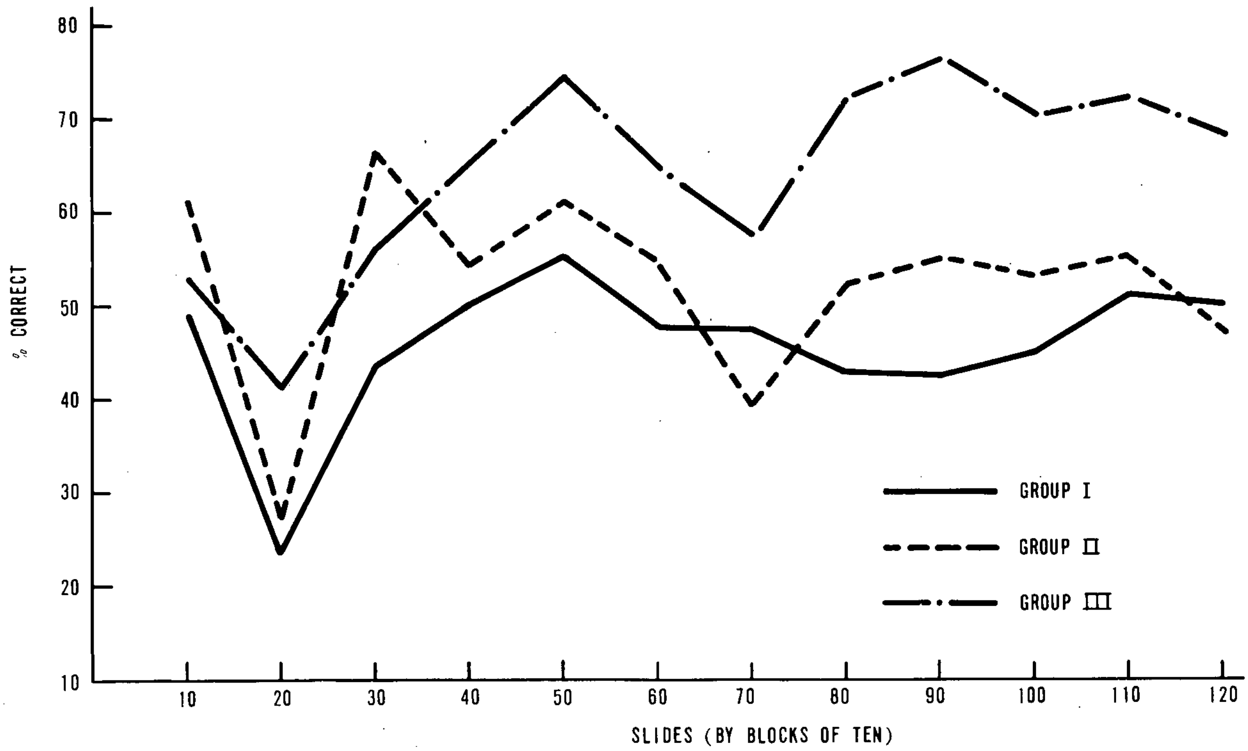

Figure G-4. Group acquisition curves.

as a useful and appropriate test of many of the hypotheses; as such, a word on the application of this statistic to these data seems in order. In the between-groups comparisons, the underlying data used to test the null hypothesis (H_0: $f_I = f_{NI}$) involve independent observations between correlated samples. Therefore, the general, well-known form of the equation

$$\chi^2 = \Sigma \left[\frac{(f_o - f_e)^2}{f_o} \right] \qquad \text{(G-1)}$$

was applied in a straightforward manner. However, within-group comparisons, involving the treatment, code, and resistance attributes, relied on data from the same subjects; hence, a genuine non-zero correlation existed and was accounted for by employing frequencies that represented "changes"; i.e., data were arranged in a four-cell contingency table as shown symbolically in Figure G-5.

It should be noted that b and c represent the discordant cases and the difference, $b - c$, divided by N equals the difference between P_1 and P_2.

With $df = 1$, a direct estimate of χ^2 in testing the significance of a difference between two correlated proportions is given by

$$\chi^2 = \frac{(b - c)^2}{b + c} \qquad \text{(G-2)}$$

The Yate's correction for continuity was applied in all cases (appropriate where $df = 1$ and any cell frequency is less than 10) because chi-square varies in discrete jumps, whereas computation by formula gives more continuous variations. Thus, in Eq. G-2 the procedure involved deducting 1 from the difference, where the difference is regarded as positive, before squaring. The net effect of this procedure is to provide a conservative estimate of χ^2, where the risks of making a Type II error (accepting the null hypothesis when it is false) are lessened.

		Slide No. 2	
		Incorrect	Correct
Slide No. 1	Correct	b	a
	Incorrect	d	c

Figure G-5. Symbolic table of frequencies of subjects who responded correctly or incorrectly on each of two slides.

Information Analysis

The purpose of the information analysis aspect of the study was to determine the relationship between delineation systems and codes, and the state of knowledge of the driver with respect to these factors. For example, if the driver *knows* a given code, then poor performance in situations in which that code is used is likely to have been produced by an inability to discriminate that code from others he knows. Thus, an assessment of system, treatment, or code discriminability was one of the goals of this effort. On the other hand, some codes may not require *a priori* knowledge because they have high intrinsic value; i.e., the meaning is immediately clear with respect to the geometric situation. The final goal relates to drivers with no *a priori* knowledge and codes with low intrinsic informational value. Here the question is: which codes can be learned more quickly through the experience of seeing the system, treatment, or code and subsequently facing the situation; i.e., which stimulus-response associations are made more quickly?

Another reason for including an "information" group in the study was to obtain data as to the potential effectiveness of delineation information campaigns of the type that could be implemented via media such as television or newspapers in much the same fashion as the public information campaigns of the National Safety Council. The attempt was to provide the information in an extremely brief and concise manner. It should be pointed out that there were several options available for providing the information to subjects. It would have been possible to hand out printed materials at the class period before the experiment so that everyone could study the material until it was learned; however, it was believed that some of the subjects may have given the material only a cursory inspection and others would study it enough to learn all the codes. This would have resulted in a differential within the group and would have tended to mask any differences that may have existed between the "information" and "no-information" groups. The other alternative, and the one chosen, was to provide the code information in the form of a lecture immediately before the experimental session. This had the advantage of ensuring that all subjects had equal exposure to the material. The disadvantage was the problem of retention and recall. However, it was believed that the short time between the lecture and the test situation would mitigate this problem to some extent.

The material provided to the "information" group (Group II) is presented in Figure G-2. As can be seen, this material would represent a fairly minimal information campaign via the media and is brief enough to be feasibly included in driver licensing manuals.

The results of the comparisons between Group I (no-information) and Group II (information) are generally in the expected direction; i.e., the expectation being that Group II would perform better. However, no such clarity exists with respect to the statistical analysis.

The first stage in the analysis consisted of a group comparison involving the slides from all situations. The second stage was a series of comparisons involving each situation individually. Table G-5 gives the percent correct response for each group, together with the obtained chi-square values resulting from the test for correlated differences. When performance is collapsed across all situations, the information group (II) had a higher mean percentage correct, but the difference failed to achieve statistical significance at the 0.05 level.

This analysis included all of the slides except those designated as "dummy" slides. In reviewing the individual situation comparisons, the reason for the nonsignificant results when comparing across situations becomes apparent; that is, the small negative difference observed for the ramp and small positive change for the curve situations offset the large differences observed for the other two situations. Although there is no certainty as to the reason for the significant "information" effect in two of the situations and the lack thereof in the other two, there is one tenable explanation. A review of all stimuli shows that the lane drop and stop approach situations used a fewer number of, but more unique codes than the curve and ramp situations. Thus, for the information group (II) there was greater certainty; i.e., fewer reasonable response alternatives. It will be recalled from the review of the human information processing literature that any reduction in the number of response alternatives has the effect of reducing uncertainty and, therefore, enhancing performance. Apparently, this information processing factor was manifested here. For example, amber was given to Group II as a color code for ramps, outside of right curve, and roadside hazards. Thus, for Group II, any stimulus slide that included amber, but included relatively few other cues, had several reasonable response alternatives; e.g., ramp, tangent (with roadside culverts or other hazards), and curve. However, the colors purple and red were associated only with the lane drop and stop approach situations, respectively. In summary, this response uncertainty for ramps and curves increased the probability of an incorrect response for the Group II subjects and, therefore, had the effect of reducing differences between the two groups.

The foregoing discussion also bears on observed decrease in performance for the ramp situation. As can be seen from Table G-5, the information group had 6.77 percent fewer correct identifications than the no-information group. Here it is possible that the information group was responding primarily to color cues (where amber was involved)* rather than to pattern cues, which would be the most likely cue to be used by the no-information group. This would imply that in providing drivers with information, one must be extremely careful to direct their attention to the total cue field rather than to specifics. This, of course, obtains only where a given cue, such as amber, is applied to a number of situations.

The over-all implication of these results is that any color cue used should be unique with respect to the geometric situation to which it is applied. In this way, as soon as the driver sees the color he will at least know which gross maneuver is required (i.e., stop, slow, turn, change lanes, etc.); then, when he arrives at the transition point, he will be better prepared to negotiate the specific geometry of the situation.

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* One result that is difficult to explain is that the no-information group performed better than the information group on the ramp slide wih an all blue treatment (slide 75). The most logical explanation that the research staff could come up with is that this slide was presented before the lane drop slide involving purple posts (slide 81) and perhaps the blue on the ramp was misperceived as purple until some basis for comparison (i.e., viewing the purple hue) existed.

Treatment Analysis

Exit Ramp Treatment

No reliable differences were found in pairing the first eleven slides listed in Table G-6 (i.e., slides 94 through 112). A review of the colors used in these systems and the strength of performance suggest that blue on the ramp is an effective treatment. Even slide 75, which has no false gore treatment, was among the better treatments and was significantly better than slide 17, which is a fairly typical treatment of amber posts on the ramp and in the physical gore. Because Group I was given no information as to color codes, the relatively better performance of those systems having a blue component would lead to the suggestion that blue has some intrinsic informational value. However, because there is no apparent cultural or experimental bias operating here, this suggestion does not seem at all tenable. Further analyses of blue vs amber were performed where all blue and amber systems (matched pairs in all elements except color) were collapsed to test for the difference attributable to color. With the systems collapsed in this way the results indicated a 79 percent correct identification for blue systems and a 58 percent correct identification for amber systems. A one-way test of the difference resulted in a value of χ^2 that was not significant at the 0.05 level.

The results of a second-stage analysis that involved a comparison of the six individual slide pairs where each pair element varied only with respect to color (i.e., slide 66 vs 94; 104 vs 60, etc.) are given in Table G-7.

Curve Treatment

Perhaps the most clear-cut results in the entire study involved the utility of the curve treatment that produced the highest number of correct identifications—the post-mounted shape. Table G-8 shows that this treatment produced a 100 percent correct response, suggesting that the shape, which was constructed of two straight pieces of mounted reflective sheeting placed at approximately a 45° angle to each another, has high intrinsic informational value. To test the hypothesis that such a delineator would be useful even under heavy fog conditions where only a single element may be seen, a slide with a single shape was included in the test. The single shape was evaluated against a single post reflector of the type typically used. The single shape (slide 28) resulted in 83 percent correct identifications, whereas the single post resulted in 11 percent correct identifications. Table G-2 shows that the single shape resulted in a higher percentage of correct identifications than did most of the other treatments, regardless of the number of elements.

Other than shape posts, those systems that included center-line RPM's yielded the highest identification scores, regardless of the post configuration with which they were used.

Because of the observed difference between the right and left curves, the results of the post-only configurations were inconclusive.

TABLE G-5

COMPARISONS OF NO-INFORMATION GROUP (I) WITH INFORMATION GROUP (II)

ITEM	CORRECT RESPONSE (%) GROUP I	GROUP II	OBTAINED χ^2
All situations	48.34	55.34	0.46
Lane drop only	27.57	47.02	6.34 [a]
Stop approach only	43.51	64.88	4.20 [a]
Ramp only	68.95	62.18	0.34
Curves only	45.76	48.00	0.054

[a] Significant > 0.05 level.

TABLE G-6

EXIT RAMP TREATMENT SUMMARY

SLIDE NO.	PERCENT CORRECT	RAMP OUTSIDE	RAMP INSIDE	GORE FRONT	GORE ACTUAL
94	94	Amber	—	Clear RPMs	—
60	94	Blue	Blue	Clear RPMs	—
33	89	Clear	Clear	Clear RPMs	—
45	89	Amber	—	Paint	Amber posts
84	89	Blue	—	Split B/C RPMs	Split B/C posts
23	83	Amber	Amber	Paint	—
91	83	Blue	—	Paint	—
75	72	Blue	—	—	Blue posts
66	72	Blue	—	Clear RPMs	—
104	67	Amber	Amber	Clear RPMs	—
112	61	Blue	Blue	Paint	—
116	61	Clear	Clear	Paint	—
25	61	Amber	—	Paint and C RPMs	Amber posts
6	50	Amber	—	Paint	—
35	50	Amber	—	Paint	Split A/C posts
73	33	Amber	—	Split A/C RPMs	Split A/C posts
17	22	Amber	—	—	Amber posts

TABLE G-7

BLUE/AMBER TREATMENT COMPARISON (EXIT RAMPS)

BLUE TREATMENT		AMBER TREATMENT		
SLIDE NO.	PERCENT CORRECT	SLIDE NO.	PERCENT CORRECT	χ^2
66	72	94	94	2.25
60	94	104	67	3.20
84	89	73	33	8.10[a]
112	61	23	83	1.13
91	83	6	50	4.17[a]
75	72	17	22	5.82[a]

[a] Significant at the 0.05 level or beyond.

Lane Drop Treatment

Table G-9 shows the rather poor performance of Group I on the right * lane drop situations. Of all the systems used, the clear post-only treatment (the one most likely to be used on a pavement width transition) was the worst, regardless of the color. Of course, it was not expected that the Group I subjects would show differential performance as a result of color used. It should be noted that whereas the no-information group showed chance performance on the purple post configuration, the information group correctly identified this situation 50 percent of the time.

The two treatments that resulted in the most accurate identification performance were: (a) amber RPM's, and (b) amber pavement arrows plus amber shape arrows (slides 118 and 22), respectively. No conclusions can be drawn with respect to the addition of pavement arrows to any given treatment. As can be seen in Table G-9, the addition of pavement arrows to purple posts (slide 98 compared with slide 81) or amber posts (slide 3 compared with slide 16) produced an increment in performance, but the difference was not statistically significant. However, the addition of pavement arrows to amber RPM's (slide 102 compared with slide 118) produced a decrement in performance. Although there may be an interaction between pavement arrows and other treatments, the nature of this interaction cannot be determined on the basis of the data obtained. Inspection of the confusion index values (Table G-12) indicates that the pavement arrow treatment led to the situation being incorrectly identified as a turn-slot in many cases. The relatively good performance produced by the combination of shape arrows and pavement arrows (slide 22) suggests that perhaps the shape arrows have some intrinsic informational value associated with them. Unfortunately, it was not possible to include those stimuli against which to directly compare this system configuration; thus, the question of intrinsic value here must remain only as a suggestion.

The final comparison that merits discussion is that of the effects of the sign usually associated with pavement width transitions. A comparison of slide 37 (amber posts on the taper together with a typical sign) and slide 16 (amber posts only on the taper) shows that although the sign produces an increment in identification performance, the difference is not statistically significant.

* Because left lane drops were not duplicated for all treatments used, these were not included in the table.

Stop Approach Treatment

The first analysis performed for the stop approach situation was to determine whether a two-line system (i.e., RPM's and edge posts) resulted in better performance than did a one-line system. No significant difference was found.

TABLE G-8

CURVE TREATMENT SUMMARY

SLIDE NO.	PERCENT CORRECT	DESCRIPTION		
		CENTER LINE	OUTSIDE	INSIDE
		(*a*) Right Curves		
63	100	—	Amber shape posts	—
76	89	Amber RPM	—	Clear posts
54	83	Amber RPM	—	—
67	78	Amber RPM	Amber posts	Clear posts
40	72	Amber RPM	Amber posts	—
42	56	—	—	Clear posts
58	29	—	Clear posts	—
21	22	—	Amber posts	—
31	11	—	Clear posts	Clear posts
29	6	—	Amber posts	Clear posts
		(*b*) Left Curves		
69	53	—	Clear posts	Clear posts
14	44	—	Amber posts	Clear posts
8	44	—	Amber posts	—
92	24	—	Clear posts	—
12	18	—	—	Clear posts

Although the binocular rivalry study (Appendix H) showed that a two-line system was the stronger cue with respect to detection, this strength does not contribute to improving identification performance. The mean percentage correct for all two-line systems was 37.9 percent, whereas for the one-line systems it was 41.1 percent, a difference of 3.2 percent. Table G-10 shows level of performance, together with a description of all stimuli.

In order to have some basis for comparison, slide 62 (an all clear system) was included as a test slide. As expected, this stimulus resulted in the lowest percentage identifications. With the exception of slide 99, all systems that included a clear component (either center-line or edge treatment) resulted in lower identification performance scores than did those systems composed entirely of red.

To assess the value of the STOP sign stimulus when used in conjunction with a system, slides 57, 95, and 1 (which did not include a STOP sign) were compared with slides 103, 72, and 99; the latter three stimuli were the same system configuration, but with a STOP sign included. Although the chi-square analysis showed that none of these comparisons was significant at the 0.05 level, the actual performance differences for pairs 99/1 and 103/57 merit some discussion. In both of these cases, the percentage identifications showed a 100 percent difference in performance in favor of those systems that included the STOP sign. The other comparison (i.e., 95/72) showed only a slight difference in favor of the STOP sign configuration, but here the system tested had an edge treatment of red posts; thus, one would expect the STOP sign to have less relative strength.

The STOP sign had the effect of enhancing identification performance on a system with a clear component to a level comparable with the all-red systems. A further indication of the relative importance of a STOP sign is that the only all-red system on which performance was below 50 percent was the one on which no STOP sign was used (i.e., slide 57). The observed effects of the STOP sign for purposes of identification are consistent with the results of the binocular rivalry study, which showed that systems that included the STOP sign provided stronger perceptual cues. Thus, for purposes of both detection and identification, care should be taken by the highway engineer to ensure that the STOP sign is visible at an appropriate distance from the stop approach area. Where this is not possible, due to geometry, a red post configuration is suggested in order to provide the driver with warning of the stop situation. Although the discussion of the STOP sign may seem to be documenting the obvious, the reason for its inclusion was that in visits to high-accident stop approach sites, a frequently observed problem was that the STOP sign was not visible due to site geometrics and/or growth of vegetation.

TABLE G-9

LANE DROP TREATMENT SUMMARY

SLIDE NO.	PERCENT CORRECT	DESCRIPTION
118	44	Amber RPMs
22	39	A pavement arrows+A shape arrows
98	29	A pavement arrows+purple posts
37	28	A posts+sign
102	22	A pavement arrows+amber RPMs
3	22	A pavement arrows+amber posts
16	18	Amber posts
81	17	Purple posts
53	17	Clear posts

TABLE G-10

STOP APPROACH TREATMENT SUMMARY

SLIDE NO.	PERCENT CORRECT	CENTER LINE	EDGE
83	56 [a]	—	Conv. red posts
95	56 [b]	Red RPM	No. 1 red posts
103	56	Red RPM	—
82	56	—	No. 1 red posts
72	50	Red RPM	No. 1 red posts
99	50	Red RPM	No. 1 clear posts
57	28 [b]	Red RPM	—
74	28	40/40 clear RPM	Conv. red posts
19	22	40/80 clear RPM	Conv. red posts
1	22 [b]	Red RPM	No. 1 clear posts
62	11	—	Conv. clear posts

[a] Slide 56 (same system configuration as slide 83) was not included here because it was taken at a nearer distance than all of the others listed. This had the effect of making the STOP sign a more dominant cue. Performance on this system was 89 percent correct identification.

[b] No STOP sign.

Code Resistance to Clutter

The degree to which the coding of situation identification information can be accomplished via delineation is in part dependent on the environment in which it is used. Inasmuch as it is not feasible to legislate against the use of house lights, and it is desirable to illuminate the roadway, etc., the nighttime environment for delineation systems may contain other stimuli that, as far as delineation is concerned, can be classified as "visual noise" or "clutter." These stimuli, which are not intended to convey specific information needed by the driver to anticipate a required downstream maneuver, often attenuate or degrade the meaning of systems so designed. The "clutter" culprits frequently include other delineation systems deployed downstream of the "next" transitional situation. The impact of this clutter phenomenon on the effectiveness of delineation systems has never been systematically examined, perhaps because of the tremendous diversity of form that it can assume. Although this is indeed a severely limiting constraint on the ability to design a study such that the desired generalizations are possible, the absence of a clear-cut method for classifying real-world clutter patterns should not serve as an excuse for avoiding the issue. Where a need exists to isolate coded systems that are capable of imparting "unique" information (as evidenced by the confusion index), approximations regarding the resistance of these codes to environmental degradation are not only acceptable but also desirable. Thus, although not exhaustive, the analyses of system configurations in their "pure" and "cluttered" forms that are presented hereafter serve as means for determining such approximations.

As explained previously, the clutter patterns differed across situations but were constant within a situation type. It was also noted that the clutter patterns, although randomly generated, were tailored to remove elements that would tend to destroy a good simulation of typical environmental noise (e.g., clutter stimuli were removed from the roadway in the foreground, etc.). Where reversed images were employed (curves and lane drops) to maintain control over all variables except for "direction," the clutter pattern was also reversed. Consequently, the comparisons to be presented were ordered by situation type and direction so as to preserve the integrity of these controls.

Needed to order the "goodness" of the within-situation system comparisons was some form of ranking device that would allow a composite picture of the worth of the system in both its pure and degraded states. Table G-11 presents an over-all summary of the resistance of selected system configurations to clutter. The rank index (RI) is simply an ordering of the product of proportions (i.e., $RI = p_P\, p_c$). The multiplicative relationship was chosen rather than an additive one because the latter would fail in ordering the joint nature of performance required: (1) the system performance in its pure state, and (2) its resistance to clutter. For example, the additive index would treat a $P_1 = 1.00$ and $P_2 = 0.0$ the same as it would a $P_1 = 0.50$ and $P_2 = 0.50$, a comparison that, by inspection, shows the former system to be totally subject to the environment in terms of its effectiveness, while the latter system is 100 percent resistant. In short, the multiplicative relationship accomplishes the desired ordering. It should be noted that the p's involved here are the proportion of subjects responding with the correct situation identification. In the χ^2 tests given in the same table, the standard error of correlated proportions is accounted for by relying on the discordant cases, $b - c$ (correct on pure and incorrect on clutter vs incorrect on pure and correct on clutter), as the basic data. Again, it helps to recognize that $b - c = Np_1 - Np_2$; thus, the χ^2 test addresses itself to the question of whether or not the change in frequencies is significant. Before discussing the implications of the results in terms of treatments or codes, several factors bearing on interpretation should be discussed. Figure G-4 shows the degree of learning that took place within the experimental session. Because the over-all sequence of stimuli was randomly generated, this "learning" effect reflects both an increasing familiarity with the procedure used (probably related to temporal set) and acquisition of knowledge about the situations. This increment in performance acted as a confounding factor with respect to the analysis of clutter in that the sequential positions of the pure and clutter pair elements could account for a portion of the observed difference. In addition to the confounding produced by the separation of pure-clutter pair elements within the session, it could also occur

TABLE G-11

PURE/CLUTTER COMPARISONS

SITUATION	SLIDE SEQ. NO. PURE	SLIDE SEQ. NO. CLUTTER	COMPOSITE RANK INDEX	% CORRECT RESPONSE PURE	% CORRECT RESPONSE CLUTTER	χ^2
Right curve	63	34	1	100	78	2.25
	40	115	2	72	89	0.80
	21	41	3	22	47	1.50
	58	119	4	29	24	0.00
Left curve	8	68	1	44	47	0.25
	69	78	2	53	29	1.50
	92	51	3	24	17	0.00
	14	2	4	44	6	5.14 [a]
Lane drop	118	5	1	44	39	0.00
	53	78	2	17	29	0.00
	81	43	3	17	22	0.00
	16	86	4	18	18	0.17
Stop approach	83	55	1	56	28	2.29
	99	44	2	50	28	1.13
	57	8	3	28	11	1.50
	62	24	4	11	11	0.25
Exit ramp	23	9	1	83	83	0.00
	112	38	2	61	83	1.50
	75	50	3	72	67	0.00
	6	49	4	50	67	0.57
	84	32	5	89	33	8.10
	73	90	6	33	72	4.00 [a]
	17	108	7	22	83	9.09 [a]

[a] Significant at > 0.05.

because a "clutter" slide appeared before its "pure" counterpart.

Table G-11 shows that very few of the systems tested resulted in a significant difference in identification accuracy when the pure and clutter pairs were compared. Of those that were statistically significant, two of the differences were in a direction that was the opposite of that anticipated. The increment in accuracy for pairs 73/90 and 17/108 cannot be explained. Any attempt at explanation falters when the argument is applied to other pairs. Because most of the differences between pairs were not statistically significant, indicating a high resistance to clutter, it is the change in ranking between the pure and clutter systems that is focused upon here, inasmuch as the raw percentages represent the best indicator of over-all relative performance. It will be recalled that the stimuli used in the clutter analysis were selected before performance data for any given system was available. Hence, not all of the "better" pure systems had clutter correlates. However, an attempt was made to cover a range of treatments or systems within each situation in the *a priori* selection. For this reason only the general effects of clutter upon systems, treatments, or treatment attributes can be derived by considering the manner in which the "pure" rankings change when the clutter rank index is applied. For the remainder of this discussion, then, parallels are drawn, where possible, between the rankings given in the section on treatment analysis and the composite rank index that results from a consideration of clutter.

With respect to curve delineation, it is clear that the post-mounted shapes (slide 63) resulted in the most accurate identification performance and also showed high resistance to clutter. It will be recalled that even the single shape (slide 28) yielded a high level of performance (i.e., 83 percent correct identifications for Group I). Considering the rest of the systems used for curve delineation, the only change in the rankings when clutter is included is the reversal of the clear-outside and amber-outside systems, which suggests that the clear post system is more vulnerable to environmental clutter. It should be noted that the clutter patterns were composed of both clear/white, and yellow/amber elements, the yellow being a simulation of background house lights, which were subjectively evaluated in the field to have an amber cast. The higher resistance of amber posts was generally upheld in the left curve rankings, where the "amber outside" configuration replaced "clear both sides" as the "best" system.

The effect of clutter is not discernible for the lane drop group, primarily because of a range curtailment (i.e., performance on the pure system was at or below chance expectancy); hence, further degradation was difficult if not impossible to measure. In the one instance where this was not the case, it can be seen that the amber RPM system (slide 118), which held top ranking in the treatment analysis, lost little in performance.

None of the systems used in the stop approach set showed a statistically significant degradation under clutter conditions, nor did any of the systems show a positional change in rank. Somewhat surprising is the percentage change observed for the three systems using red. Because none of the elements in the clutter pattern was red, one would have predicted a negligible change in the percentage rather than the nearly 50 percent decrease observed.

The change in rankings for exit ramps when the clutter rank index is applied indicates that a painted gore will result in better performance in a visually noisy environment than will RPM's on the gore. Because of the RPM's are seen as point sources of light, as are the majority of the clutter elements, this seems to be a reasonable supposition. It should be noted that the ramp used in these slides was newly painted and was, therefore, an extremely dominant cue.

Confusion Index

The development of the notion of a confusion index stemmed primarily from the lack of standardization of existing delineation codes (between and within states), which manifested itself in the form of indiscriminate use of the same treatment, color, and perceptual pattern for a host of roadway situations. Consider, for example, the use of amber reflective post delineators that in practice are found in the delineation of roadway obstructions, acceleration and deceleration lanes, drainage ditches, pavement width transitions, median guardrail, the outside of right-hand curves, etc. To a lesser extent, other delineation system configurations suffer the same lack of discriminability, leaving the driver with little information, other than the message: "A change is about to take place." Frequently, even this "readiness" information is denied him because of system/environment interactions. What was attempted, therefore, was to derive a metric for examining the confusion in the identification of the test situations. The notion was that if one is able to identify where the errors are likely to occur, and which treatments and/or systems are among the more powerful discriminators, the system capability could be married to the situation identification need, enhancing the information value to the road user. The first portion of this objective was addressed in a descriptive fashion using the incorrect response alternatives, given the correct situation identification, as the basic data. These data are summarized for the naive sample in Table G-12, in which the values represent a ratio of the number of times a specific incorrect response was selected (O_T = No. of opportunities taken) to the number of times that specific incorrect alternative was presented (O_P = No. of opportunities presented) for a given test situation(s), or

$$C\,I_S = O_T / (N\,O_{PS}) \qquad \text{(G-3)}$$

in which N is the number of subjects in the group.

The upper half of Table G-12 is symmetrical in terms of the test situations identified, with the diagonal cells of the upper half containing the percentage of correct responses given for the indicated situation. All other entries are exposure-adjusted indices of the degree of confusion in identification. Because the composition of the set of response alternatives varied from slide to slide, the ratios do not add to unity. Rather, the interpretation is that the ratio represents the probability that a particular incorrect situation identification will result, given that the incorrect situation occurs as an alternative for a specific correct response. The mechanism for relating this interpretation to driver behavior is to consider the contingent probability that the alternative will occur as representing the behavioral response repertoire that the driver generates as a function of his experience with different system configurations. When collapsing across system configurations (the case in point), one is able to express the likelihood that a particular type of identification error will be made. Thus, when considering all lane drop situations with taper on the left, the driver is almost twice as likely to incorrectly identify the situation as a right curve than he is to misidentify it as an exit ramp.

An interesting extension of this confusion index is to

TABLE G-12

CONFUSION INDEX, GROUP I

	CORRECT SITUATION [a]					
INCORRECT SITUATION	LEFT LANE DROP	RIGHT LANE DROP	LEFT CURVE	RIGHT CURVE	EXIT RAMP	STOP APPROACH
Left lane drop	31.5 17/54	2.8 1/36	2.8 1/36	11.1 8/72	4.0 5/126	—
Right lane drop	—	25.9 42/162	11.1 4.36	16.7 6/36	0	14.4 13/90
Left curve	13.9 5/36	3.7 6/162	34.0 49/144	16.7 12/72	5.6 3/54	7.4 4/54
Right curve	37.0 20/54	5.5 1/18	18.3 23/126	50.0 99/198	5.2 14/270	—
Exit ramp	19.4 7/36	18.1 13/72	7.4 4/54	10.2 11/108	69.0 211/306	9.3 5/54
Stop approach	0	11.1 2/18	0	19.8 25/126	—	43.5 94/216
Tangent	11.1 2/18	5.5 1/18	52.8 38/72	38.9 21/54	1.1 1/90	46.8 59/126
Obstruction	—	11.1 6/54	20.8 15/72	11.1 4/36	—	3.3 3/90
Turn slot	11.1 2/18	22.2 20/90	5.6 2/36	—	—	16.7 9/54
Crossover	—	7.4 4/54	5.6 2/36	8.3 6/72	—	4.2 3/72
Diverge	—	22.2 4/18	—	—	36.4 59/162	—
Merge	—	5.5 1/18	—	—	5.6 2/36	—
Wrong way	—	—	—	—	—	0.9 1/108
Railroad crossing	—	—	5.6 1/18	5.6 1/18	—	—
Entrance ramp	—	8.3 6/72	—	4.2 3/72	3.4 8/234	9.7 7/72
Bridge	—	—	—	—	—	16.7 6/36
No pass	—	11.1 2/18	—	—	—	—
Crossroad	5.5 1/18	—	—	—	—	—

[a] An empty cell (row by column) means that the incorrect situation alternative (row) did not appear in any response set that contained the corresponding column's correct response.

factor in the cost of errors of misidentification. Entering the table horizontally, it can be seen that there is a strong tendency to misidentify nontangent situations as "target." This error type has high relative cost in terms of safety, because it implies a no-change condition (or, in terms of the earlier modeling effort, a quasi-steady state) when, in fact, a transitional situation is imminent. For example, when the situation is a stop approach the information should result in a decision to decelerate and eventually stop. Misidentifying the stop approach as a tangent (information-erroneous though it may be) may result in an unhampered continuation through the stop limit. It should be clear that the potential cost is considerably higher erring in this direction than it would be if the misidentification were reversed (i.e., identifying a tangent section as a stop approach).

Finally, it should be recognized that those delineation systems whose over-all performance is shown to be superior should be reserved for situations where the confusion index is highest, and the probability of occurrence of particular types of errors of misidentification and their associated relative costs have been considered.

Identification Performance: Cue Utilization

In designing the second part of this study the intention was to determine whether or not differential performance on situation identification could be characterized by a differential use of available cues. In this analysis, the situation identification responses were scored, subjects were ranked on these scores, and two subgroups were formed representing high performers and low performers. Next, a score was derived for each of the cue factors (color, treatment, location). These scores (S_f) were generated for each factor, for each slide, in the following manner:

$$S_f = \left(3C - \sum_{i=1}^{3} e_i \right) / k \qquad \text{(G-4)}$$

in which k is the number of part scores, e is an error of commission, and C is the number of parts correct. In other words, guessing was penalized by weighting the scores such that errors of commission cost more than errors of omission. In this way an $N \times 120$ matrix was generated, each cell of which contained five score values; viz., (1) situation identification, (2) color, (3) treatment, (4) location, and (5) a total cue factor score. These data were then summarized for the two performance groups by summing over slides. The results of these manipulations are given in Table G-13.

The observed performance differences in terms of the means given at the foot of the table do not appear at first glance to support any differential use of cues between the groups; however, when these same data are subjected to a correlational analysis, discriminating trends in the use of cue factors become more apparent. Table G-14 gives a symmetric intercorrelation matrix for both groups, with the high performers above the diagonal and the low performers below (total scores were not examined in this analysis because the intent was to isolate specific cue factor contributions to the variance in identification performance).

The indication of "an apparent trend" is just that, because the data preclude any strong statements regarding the reliability of observed correlation coefficients (r's)—i.e., whether or not they differ significantly from zero—or differences between r's—i.e., whether or not the r's come from the same population. This difficulty in uncovering definitive relationships stems from the rather small sample size(s) that resulted from splitting the group. The alternative of collapsing across groups before splitting into the high and low subgroups was not considered acceptable because the data would have been confounded by the inclusion of experimental codes and any results so obtained could have been misleading.

Despite this pessimistic vein, it would be foolish to disregard the observed trends based on conventional rejection levels. Rather, the reader is urged to examine the obtained relationships and consider their corresponding probability estimates lest potentially useful results be lost. For example, r_{14}, the correlation between locational cues and situation identification for the high performers, although failing to reach significance at the 0.05 level, would have occurred on the basis of chance only 13 times out of 100. Considering the low risk involved in rejecting the null hypothesis, it would be prudent to recognize that locational cues do, in fact, contribute to situation identification for the high performance group, whereas no such relation-

TABLE G-13

CUE UTILIZATION SUMMARY SCORES BY SUBJECTS BY PERFORMANCE, GROUP I

HIGH PERFORMERS						LOW PERFORMERS					
SUBJ. NO.	ID SCORE	COLOR	TREATMENT	LOCATION	TOTAL	SUBJ. NO.	ID SCORE	COLOR	TREATMENT	LOCATION	TOTAL
3	12	47.5	35.5	19.0	102.0	15	7	57.0	38.3	14.7	110.0
11	11	42.5	34.0	16.3	92.8	6	7	48.0	42.5	16.7	107.2
7	11	48.0	39.5	23.5	111.0	2	6	55.0	36.2	16.5	107.7
4	10	43.5	27.5	14.0	85.0	10	6	40.5	38.5	20.8	99.8
5	10	48.5	32.5	17.1	98.1	12	6	43.5	31.0	15.3	89.8
14	10	47.0	32.2	7.4	86.6	18	6	42.5	19.5	16.0	78.0
13	9	41.5	36.2	10.3	88.0	16	5	49.0	32.0	15.4	96.4
$\bar{X}$	10.43	45.5	33.9	15.4	94.8	$\bar{X}$	6.1	47.9	34.0	16.5	98.4

TABLE G-14

INTERCORRELATION MATRIX [a]

	1 IDENT	2 COLOR	3 TRTMNT	4 LOCATION
1. Ident	.	0.440	0.297	0.678
2. Color	0.310	.	0.210	0.437
3. Trtmnt	0.475	0.393	.	0.490
4. Location	−0.058	−0.541	0.288	.

[a] High performance group appears above the diagonal; low performance group, below.

ship exists for the low performance group ($r_{1,4} = -0.058$). Roughly the same opportunity exists to observe, only on the basis of chance, the *difference* between the $r_{2,4}$'s (color and location): high group, $r_{2,4} = 0.437$; low group, $r_{2,4} = -0.541$. This difference, when tested for significance using the log transformation to standardize the r's to Z scores, yields $Z = 1.519$, a normally distributed difference score that could be expected to occur on the basis of chance alone approximately 13 times out of 100. Because of the negligible (given the small sample size) differences in the remaining comparisons, further inference becomes implausible. It does appear, however, that the locational factor that includes typical geometric and pattern cues does serve to discriminate between good and bad performance in situation identification. Furthermore, it would seem that if color is to be employed as a code for situation identification it would be advisable to consider its role as indirect or second-order. That is to say, the effect of color, judging from the relative direction and magnitude of the $r_{2,4}$'s might be to suppress the positive attributes of the locational factors. If, after further study, these suppositions hold, the results would be directly applicable to an information dissemination program. Spot public service television announcements and a tailoring of driver education programs to provide delineation code information are but two forms of many that such a program could take.

APPENDIX H

TARGET VALUE—A LABORATORY EVALUATION OF ALTERNATIVE STOP APPROACH SYSTEM CONFIGURATIONS *

The use of perceptual phenomena such as binocular rivalry for a laboratory evaluation of roadway delineation is based on the opinion that perceptual effectiveness is the only logical precursor to operational effectiveness. Further, not only does the controlled environment of the laboratory permit control of many variables that cannot be controlled in the field, but in addition the effort is much less time-consuming than most types of highway field research. Inasmuch as the goal of this study was to evaluate the relative perceptual effectiveness of a large number of system configurations, the laboratory setting was advantageous. The reason for the choice of technique is that in the binocular rivalry situation something similar to a competition between two different processes obtains, and what is perceived represents the outcome of this competition. An analysis of the perceptual report allows one to determine the relative effectiveness of the processes initiated separately in the two eyes. That is, when two stimuli are simultaneously presented, the strength of one relative to the other may be such that only one is reported. If they are of equal strength, each will be reported approximately 50 percent of the time under multiple judgments. The percentage of time one is reported then is the indication of relative perceptual strength or monocular dominance.

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In short, binocular rivalry permits detection and measurement of perceptually relevant differences between targets and is therefore a meaningful way in which to evaluate the perceptual effectiveness of delineation systems.

TREATMENTS

The treatments involved in the stop approach study were post delineators and raised pavement markers (RPM's). These treatments were varied with respect to spacing and color. One other variable involved was the existence or nonexistence of a STOP sign. The reason for the inclusion of this variable was that a number of "problem" (high accident) stop approaches had been visited by project personnel, and at a number of these the STOP sign was hidden by bushes, banks, etc. Therefore, it was believed that the systems to be tested should convey the appropriate message even if the STOP sign cue was not available and, further, should determine whether any of the system configurations were particularly resistant to the lack of the STOP sign cue. The treatment specifications for the photographic stimuli used for the comparisons are given in Table H-1.

In all cases, the stop approach treatment was carried from the point of the STOP sign to a point 720 ft back. Those stimuli marked "N" (near) indicate that the photographic stimuli were taken at a point 720 ft from the STOP sign. Those marked "F" (far) indicate that the photograph was taken at a point 1,120 ft from the STOP sign.

Regarding the various configurations and notations in Table H-1, the following points should be noted:

1. RPM spacing notated as 40/40 indicates that 40-ft centers were used over the entire 1,120-ft site. The 40/80 notation indicates that 40-ft centers were used for the first 720 ft and switched to 80-ft centers for the final 400 ft.
2. RPM color notated as R/C indicates that red RPM's were used for the 720-ft stop approach area and clear RPM's were used for the next 400 ft; i.e., the foreground of the photographic stimulus. This also obtains for the R/C notation of the post configuration.
3. The #1 notation on post spacing indicates a geometric spacing, with the first post being 10 ft from the STOP sign. Successive placement was then at a distance double the previous interval, with the restriction that no posts would be more than 200 ft apart. Thus, the actual placement, in terms of distance from the STOP sign, was 10, 20, 40, 80, 160, 320, 520, 720, 920, and 1,120 ft. In the case of red post configuration the red was carried to the 720-ft point and then switched to clear.
4. The "C" notation regarding post spacing refers to conventional spacing of 200-ft increments between posts, with the restriction that the first post was always 10 ft from the STOP sign.

For each pair used in the binocular presentation, only a single factor differed between the elements of the pair. Table H-2 gives the pairs used, and a brief description of the difference between the elements in the pair.

Although an extremely large number of new treatment systems could be designed and evaluated for the stop approach, the emphasis of this study was on various combinations of treatments that are currently in wide use.

TABLE H-1

SPECIFICATIONS OF PHOTOGRAPHIC STIMULI

PAIR	RPM'S		POSTS		STOP SIGN		LOCATION	
ELEMENT	SPACING	COLOR	SPACING	COLOR	YES	NO	NEAR	FAR
A	40/40	R/C	#1	R	x			x
B	40/40	R/C	#1	R		x		x
C	40/40	R/C	#1	R		x	x	
D	40/40	R/C	#1	R	x		x	
E	40/80	R/C	#1	R	x			x
F	40/80	R/C	#1	R		x		x
G	40/80	R/C	---	---		x		x
H	40/80	R/C	---	---	x			x
I	40/80	R/C	#1	R		x	x	
J	40/80	R/C	#1	R	x		x	
K	40/80	R/C	---	---	x		x	
L	40/80	R/C	#1	C	x		x	
M	40/80	R/C	#1	C		x		x
N	40/80	R/C	#1	C	x			x
O	40/40	C	C	R/C	x			x
P	40/80	C	C	R/C	x			x
Q	40/80	C	C	C	x			x
R	40/40	C	C	R/C	x			x
S	-----	---	C	C	x			x
T	-----	---	C	R/C	x			x
U	-----	---	C	R/C	x		x	
V	-----	---	#1	R/C	x		x	
W	40/80	R/C	C	R/C	x			x

APPARATUS

Three-Channel Tachistoscope

The unit used for the study was a Scientific Prototype Corp., Model GB, Three-Channel Tachistoscope. This device permits precise control of illumination, exposure time, and sequencing for all three channels. It also permits optical mixing (i.e., superimposition) of all three channels in any combination.

Two separate units comprise the tachistoscope: the optical system and its electronic control unit. The optical system (see Fig. H-1) consists of three chambers or channels, each containing a holder for a 5 by 7-in. stimulus card and two gas discharge lamps for illuminating the card at the appropriate time and for the appropriate time interval.

The three stimulus cards are viewed from a common viewing hood through three partially front-silvered mirrors with precisely controlled reflectivity. The function of the mirrors is to bring the three fields into a common plane and give similar visual brightness for identical illumination. Due to interference effects in the mirrors, the color match between fields cannot be made absolutely perfect. However, through the use of mirrors developed specifically for this unit, a far closer color match has been achieved than was ever before possible. Each mirror has a multi-layer face that transmits 45 percent of incident light and reflects 45 percent. The mirrors have anti-reflection back-coatings of magnesium fluoride to reduce multiple imaging.

An adjustable mask is built into each channel to permit the visual positions of the edges of the stimulus cards to be adjusted so that the cards appear stationary when channels are switched. Two additional adjustable masks are provided to permit visual masking of the walls of the box to reduce the effect of internal reflections as much as possible.

Each channel has two access slots—one on the back panel (in the light chamber) to contain the stimulus card, the other between the light chamber and the viewing hood. The latter access slot is designed to control light transmission from the light chamber via insertion of polarizers, filters, apertures, etc.

For the current study, two of the transmission control slots contain 5 × 7-in. sheets of Polaroid HN-32 linear polarizer (luminous transmittance of 32 percent, extinction transmittance of 0.005 percent), the filter in channel one being oriented vertically and that in channel two being oriented horizontally. The third channel contained an aperture card to provide a light spot (focal point) for the subject.

Viewing Point Filtration System

Mounted on the body of the T-scope inside the viewing hood is a sliding filter carriage (Fig. H-2). There are three positions in the carriage, one on either end with polarized filters and one in the middle with no filter. Each of the two polarized filters is split; that is, one half is oriented vertically and the other half is oriented horizon-

TABLE H-2

INDIVIDUAL DATA RECORDS AND TOTALS

Pair No.	Description	Pair	Block 1				Block 2				Block 3				Block 4				Block 5				Total Responses
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	Stop Sign	A	5	5	3	4	5	5	4	5	2	4	3	5	2	5	5	3	5	3	4	5	82
	No Stop Sign	B	0	0	2	1	0	0	1	0	3	1	2	0	3	0	0	2	0	2	1	0	18
2	No Stop Sign	C	0	0	0	1	3	1	1	0	1	2	0	0	2	1	0	0	3	1	0	0	16
	Stop Sign	D	5	5	5	4	2	4	4	5	4	3	5	5	3	4	5	5	2	4	5	5	84
3	Stop Sign	E	3	5	3	5	3	5	5	5	4	5	4	4	2	4	3	2	4	5	4	4	79
	No Stop Sign	F	2	0	2	0	2	0	0	0	1	0	1	1	3	1	2	3	1	0	1	1	21
4	No Stop Sign	G	0	1	2	0	2	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0	10
	Stop Sign	H	5	4	3	5	3	5	5	5	4	5	4	5	4	5	5	5	5	4	4	5	90
5	No Stop Sign	I	0	0	2	0	2	0	2	0	3	2	0	0	2	1	3	0	0	3	1	2	23
	Stop Sign	J	5	5	3	5	3	5	3	5	2	3	5	5	3	4	2	5	5	2	4	3	77
6	No Stop Sign	M	1	0	5	2	1	1	3	1	0	3	3	2	2	1	1	2	2	3	3	2	39
	Stop Sign	N	4	5	0	3	3	4	2	4	5	2	2	3	3	4	4	3	3	2	2	3	61
7*	40/40	B	5	3	3	1	3	1	1	3	3	4	4	4	2	3	2	0	3	5	3	2	55
	40/80	F	0	2	2	4	2	4	4	2	2	1	1	1	3	2	3	5	2	0	2	3	45
8*	40/40	O	0	3	2	3	3	2	2	4	2	3	3	3	3	1	2	2	2	3	2	1	46
	40/80	P	5	2	3	2	2	3	3	1	3	2	2	2	2	4	3	3	3	2	3	4	54
9	C.RPM's + R/C Posts	P	5	5	4	5	4	5	5	5	3	5	5	5	5	5	3	5	4	3	5	3	89
	R/C Posts	T	0	0	1	0	1	0	0	0	2	0	0	0	0	0	2	0	1	2	0	2	11
10	R/C Posts	T	0	0	1	0	2	1	0	0	0	1	0	0	0	0	1	0	1	1	0	1	9
	R/C RPM's + R/C Posts	W	5	5	4	5	3	4	5	5	5	4	5	5	5	5	4	5	4	4	5	4	91
11	C.RPM's + R/C Posts	O	5	5	5	5	4	5	5	5	5	3	5	5	5	4	3	5	5	3	5	4	91
	R/C Posts	T	0	0	0	0	1	0	0	0	0	2	0	0	0	1	2	0	0	2	0	1	9
12	R/C RPM's + R. Posts	F	4	5	4	5	4	5	4	5	5	5	5	5	4	5	5	5	5	4	5	4	93
	R/C RPM's	G	1	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1	7
13	R/C RPM's + R. Posts	E	5	3	4	5	2	4	4	3	4	5	4	4	4	4	5	4	3	3	5	4	78
	R/C RPM's	H	0	2	1	0	3	1	1	2	1	0	1	1	1	1	0	1	3	2	0	1	22
14	R/C RPM's + R. Posts	F	2	1	2	0	2	0	0	1	3	3	2	0	1	0	1	0	2	2	3	2	27
	R/C RPM's +C. Posts	M	3	4	3	5	3	5	5	4	2	2	3	5	4	5	4	5	3	3	2	3	73
15*	R/C RPM's + R. Posts	E	2	0	2	2	3	2	0	1	3	3	5	3	4	1	1	1	0	2	4	2	41
	R/C RPM's + C. Posts	N	3	5	3	3	2	3	5	4	2	2	0	2	1	4	4	4	5	3	1	3	59
16	R/C RPM's	G	0	0	1	0	2	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	5
	R/C RPM's + C. Posts	M	5	5	4	5	3	5	5	5	5	5	4	5	5	5	5	5	5	4	5	5	95
17	R/C RPM's	H	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	7
	R/C RPM's + C. Posts	N	4	5	4	5	4	5	5	5	5	5	4	5	5	5	5	5	5	2	5	5	93
18*	R/C RPM's	H	0	1	4	0	3	1	3	2	4	0	4	2	5	1	0	2	0	3	3	1	40
	C. Posts	S	5	4	1	5	2	4	2	3	1	5	1	3	0	4	5	2	5	2	2	4	60
19*	R/C RPM's	H	1	2	3	1	5	2	3	1	3	0	2	3	4	0	0	5	1	2	1	1	40
	R/C Posts	T	4	3	2	4	0	3	2	4	2	5	3	2	1	5	5	0	4	3	4	4	60
20*	R/C RPM's	K	3	5	4	1	4	3	5	5	5	0	2	3	2	0	0	5	0	3	4	0	54
	R/C Posts	U	2	0	1	4	1	2	0	0	0	5	3	2	3	5	5	0	5	2	1	5	46
21*	R/C RPM's	K	1	4	4	4	3	3	5	5	4	1	1	3	4	1	1	5	0	3	1	0	53
	R/C Posts	V	4	1	1	1	2	2	0	0	1	4	4	2	1	4	4	0	5	2	4	5	47
22	R/C RPM's	K	0	1	4	0	2	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	10
	R/C RPM's + C. Posts	L	5	4	1	5	3	5	5	5	5	5	4	4	5	5	5	5	5	4	5	5	90
23	R/C RPM's	H	0	1	4	0	3	0	0	0	0	0	0	0	2	0	1	0	1	1	0	0	13
	R/C RPM's + R/C Posts	W	5	4	1	5	2	5	5	5	5	5	5	5	3	5	4	5	4	4	5	5	87
24	R/C RPM's + R. Posts	J	4	2	4	5	3	5	2	2	1	5	5	3	4	4	4	5	1	3	4	4	70
	R/C RPM's	K	1	3	1	0	2	0	3	3	4	0	0	2	1	1	1	0	4	2	1	1	30
25*	R/C RPM's + R. Posts	J	0	0	2	4	1	2	1	1	2	4	5	2	2	1	4	1	0	4	3	3	42
	R/C RPM's + C. Posts	L	5	5	3	1	4	3	4	4	3	1	0	3	3	4	1	4	5	1	2	2	58
26*	C. Posts	S	5	1	4	4	4	3	3	5	3	3	0	2	0	1	4	1	1	3	1	1	49
	R/C Posts	T	0	4	1	1	1	2	2	0	2	2	5	3	5	4	1	4	4	2	4	4	51
27*	C. RPM's + R/C Posts	P	2	2	1	2	4	2	3	4	3	3	2	3	3	2	2	0	4	3	4	3	52
	R/C RPM's + R/C Posts	W	3	3	4	3	1	3	2	1	2	2	3	2	2	3	3	5	1	2	1	2	48
28	Posts (Conv. Spacing)	U	0	5	2	0	2	1	3	2	3	1	0	2	1	3	0	1	0	4	4	1	35
	Posts (#1 Spacing)	V	5	0	3	5	3	4	2	3	2	4	5	3	4	2	5	4	5	1	1	4	65

Responses of Subjects

*Indicates A Non-Significant Difference

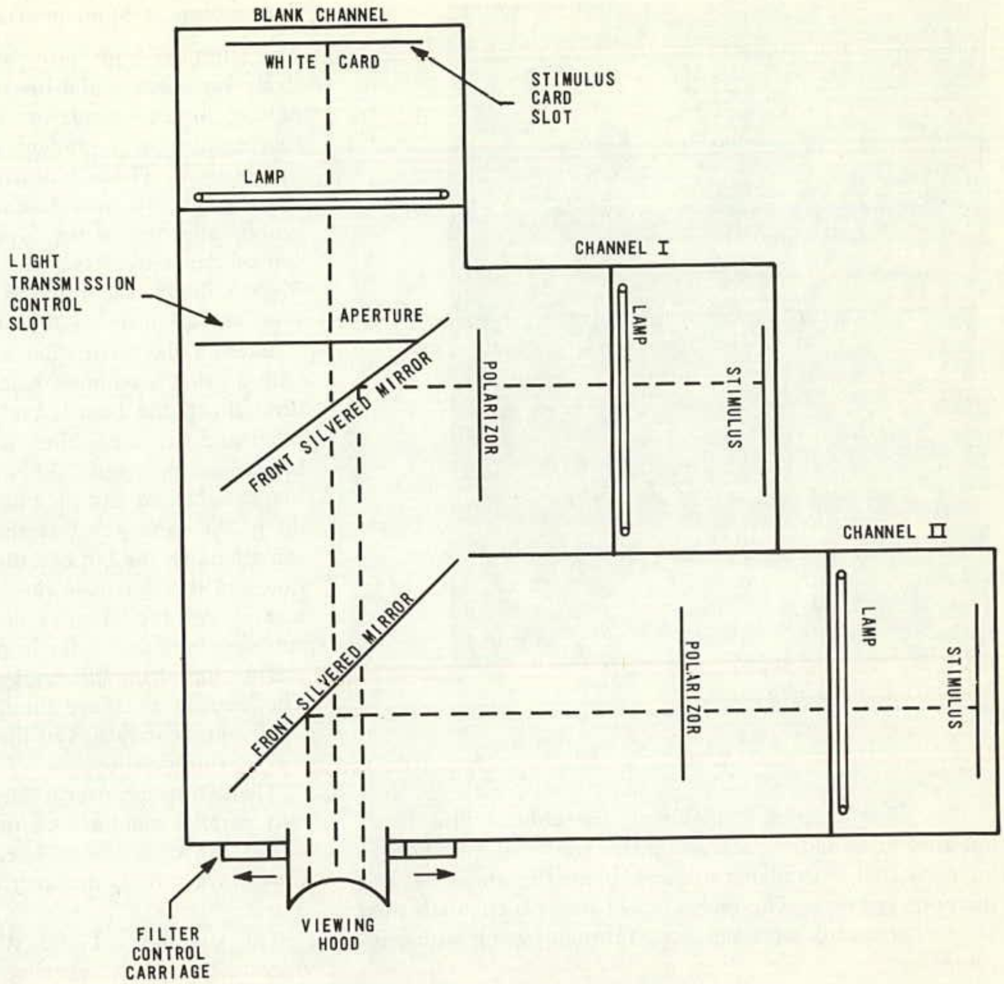

Figure H-1. Three-channel tachistoscope (Scientific Prototype Corp.).

tally. The right and left ends of the carriage have opposite orientations. With the filter in the left position the subject's right eye is therefore getting only horizontally polarized light. In the right position this situation is reversed. In the middle carriage position both eyes are getting unpolarized light.

Therefore, when the viewing filter is in position the eye with the vertical polarizer will see the channel with the vertical filter inserted in its optics and the horizontally filtered eye will see the horizontally filtered channel. When the filter position is changed, the eye/channel relationship is reversed. In the middle position both eyes see any channels that are illuminated. This filter carriage system, then, permits reversal of the eye/channel relationship without requiring a physical change in the position of the stimulus card. Such flexibility was required in order to prevent eye dominance factors from biasing the data.

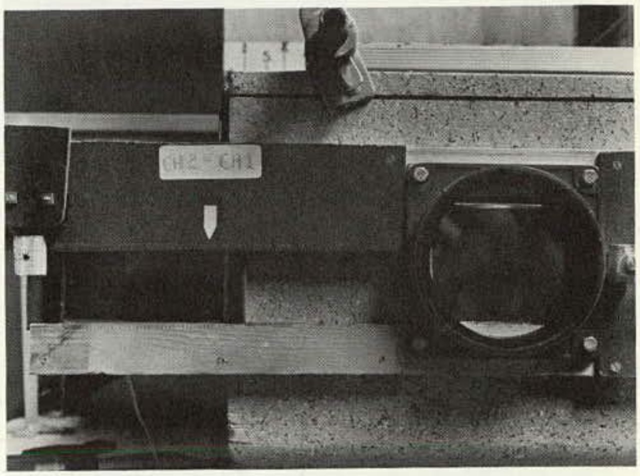

Figure H-2. Filter carriage with right set of filters in place.

Electronic Control Unit

The control unit (Fig. H-3) contains ten internally controlled logical configurations. In addition it is possible to program many other configurations to the lamp drivers through external circuitry. The unit also contains a time interval generator for each channel. These are one-shot multi-vibrators that can generate any time interval from 0.1 millisec to 110 sec through the use of a direct-reading ten-turn time control vernier and a six-range decade switch.

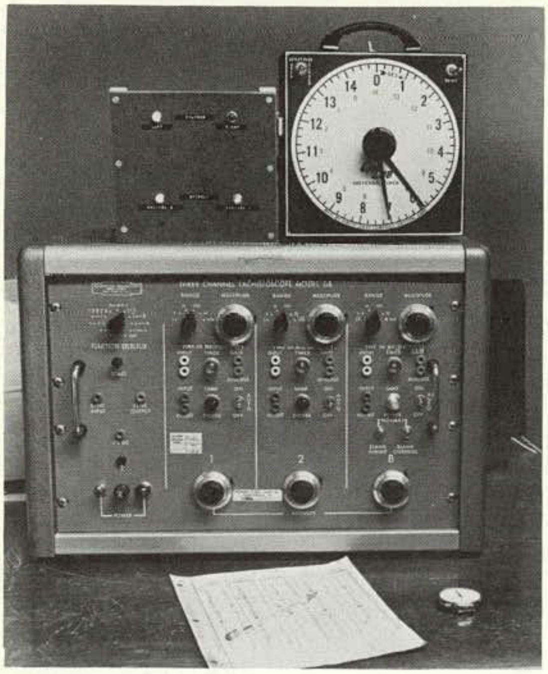

Figure H-3. Pilot light panel.

The other control available in the control unit is an intensity control for each channel. The total variation in intensity that is available in each channel is somewhat less than one log unit. The intensities of the two channels used to present stimuli were balanced through testing with pilot subjects.

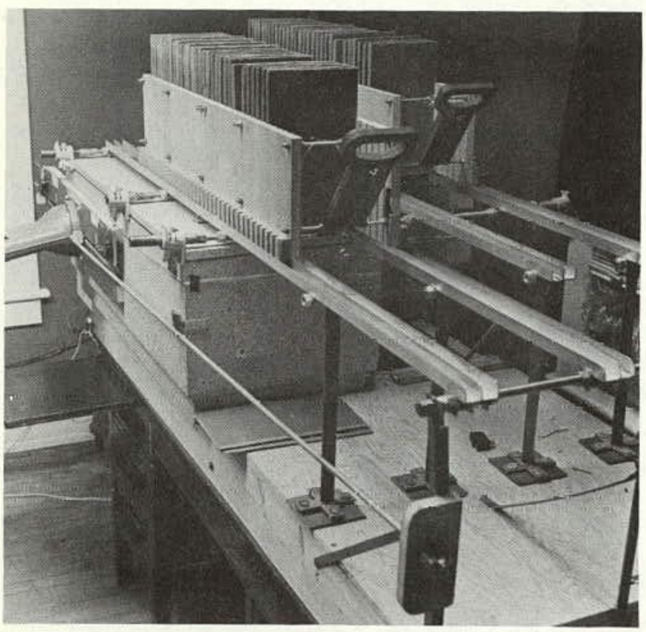

Figure H-4. Stimulus transporter system and filter carriage control rod.

Semiautomatic Stimulus Transporter System

The stimulus transporter system (Fig. H-4) allows relatively rapid sequential insertion of stimulus cards into two of the three channels of the T-scope. Slotted bins were fabricated to accommodate 35 hardboard stimulus mounting boards. These bins ride on aluminum sliding door tracks and the mounting boards (with stimulus photographs attached to the lower portion) ride on the inside rail of the track. Over the stimulus slot in the top of the T-scope body, the track is cut, allowing one board at a time to fall through the slot and into viewing position.

Each of the boards has a hole in the exact center, fitted with a nylon grommet. A length of nylon cable is threaded through all the boards and fastened at one end. At the other end the line is threaded through a block and tackle/handle arrangement. When the handle is pulled down the line is tightened and the board in the stimulus slot is pulled up to the same level as the other 34 boards. Using the same handle, the bin can then be moved to any other position and that board lowered into the stimulus slot. Registration with the stimulus slot is assured by a spring-loaded rubber wheel that rides in and out of a series of slots on the outside of the bin corresponding to those on the inside. The outside slots are numbered above the wheel and a small mirror indicates to the operator which stimulus is in the viewing position.

The two transporter tracks and bins run parallel over the two parallel channels of the T-scope. This arrangement allows the operator to operate one bin with each hand, thus moving from one pair of stimuli to another in about 3 sec.

The operator of the stimulus transporter must also operate the subject viewing filter carriage. Therefore, the filter carriage has a 5-ft rod as a handle and is easily operable by the transporter operator (Fig. H-5).

To reduce errors and running time, micro-switches detect the registration in the stimulus slot of the stimulus board in each channel and the mode of the viewing filter. These events are communicated to the experimenter (as distinct from the transporter operator) by means of a pilot-light panel (Fig. H-3).

STIMULUS PREPARATION

Site

The site used for making the stimulus photographs was a closed section of Route 220 between Mt. Eagle and Howard, Pa., leased from the Army Corps of Engineers. The closed site provided complete freedom to set up the different system configurations and photograph them without the logistical constraints of traffic control. The stop approach was set up on a tangent section with a minimum of peripheral visual cues (i.e., trees, brush, guardrails, etc.) Further, because all systems were set up on the same area, all extraneous cue factors were constant across all photographic stimuli.

The photographs were made at two distances from the STOP sign—900 ft and 1,300 ft. After final cropping of the prints the foregrounds begin at 850 ft and 1,250 ft, respectively.

Camera Equipment

The camera used to make all of the roadway photographs used in the tachistoscope evaluation was a 4 × 5 Graphflex Crown Graphic with a 135-mm Schneider lens. In all cases illumination was provided by the high beams of a Volvo 145 (single headlamps). The camera was placed between the headlights on a tripod at an average driver eye height (3½ ft).

Film and Processing

Kodak Ektacolor Type L film was used in order to obtain proper color balance from the long exposures necessary (1 sec). The film was processed normally in the C-22 process, and the 5 × 7-in. prints were made using a D mask (55 × 38 mm) on an enlarging color printer to crop out unnecessary periphery in the original negatives. The negatives were printed backward, yielding prints reversed right to left, because the mirror system in the tachistoscope reverses stimuli images right to left. Several color balances were printed. From these, one was subjectively picked, under the tachistoscope illumination, as the most realistic representative of the actual roadway. All subsequent photos used in the study were matched to this standard.

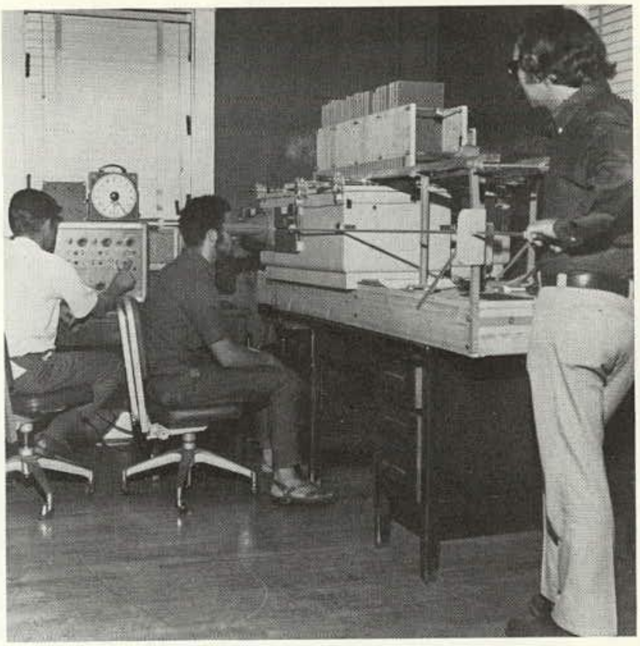

Figure H-5. Operation of T-scope and stimulus transporter system.

SUBJECTS

The 20 subjects ranged in age from 19 to 45 years. All subjects had at least two years of driving experience, with the bulk of the sample having at least eight to ten years experience. The sample was composed of eleven men and nine women. A vision test was administered to screen each subject for far acuity, depth perception, color blindness, and lateral and vertical phoria problems. An optical tester was used for this screening.

PROCEDURE

By use of the binocular rivalry paradigm mentioned previously, each subject was first given a brief presentation in which two different photographs (delineation systems) were simultaneously shown, one to each eye. Following this each element of the pair was shown individually. The brief "stimulus" presentation was of ½-sec * duration; the longer-duration "response" exposures lasted approximately 2 sec for each photograph. The subject was not told that the brief presentation consisted of two photographs. The task was to identify which of the two longer presentations was the same as the first (brief) presentation. Figure H-6 shows the relationship between the actual visual input and time and also illustrates a conceptualization of the resultant perceptual event.

Before the experimental sessions began, the instructions shown in Figure H-7 were read to each subject. Following each trial (or series of 28 pairs) the subject was given a 2- or 3-min rest before beginning the next sequence. Each sequence required 6 to 9 min, depending on how quickly the subject responded.

* The exposure durations used were chosen on the basis of pilot data.

EXPERIMENTAL DESIGN

The paired comparison design required that each subject be presented with five repetitions of each pair in order to satisfy judgment reliability requirements. Thus, in a given experimental session the entire sequence of pairs was given five times, with a short rest period between trials. To prevent any intertrial visual fatigue bias, and/or to prevent any sequence learning effects, the starting point in the sequence was varied on each of the five trials. A block of four subjects was used for each separate sequence. The sequence was determined by assigning each pair a number, and randomly assigning the pair to a position in the sequence.

The filter condition used to control which eye received which element of the stimulus pair was assigned such that eye dominance factors would be balanced within subjects. Also, the response sequence presentation (i.e., which element in the pair was shown first following the simultaneous presentation) was balanced to prevent a response-sequence bias.

RESULTS AND DISCUSSION

The conclusions here are based on an analysis using the Wilcoxon Matched-Pairs Signed-Ranks Test. The 0.05 level of significance was used for the evaluation. Table H-2 gives the distribution of responses for the individual subjects in each block. The columns represent the sum of five repetitions for each subject. Also indicated are those pairs the Wilcoxon analysis showed to be significantly different.

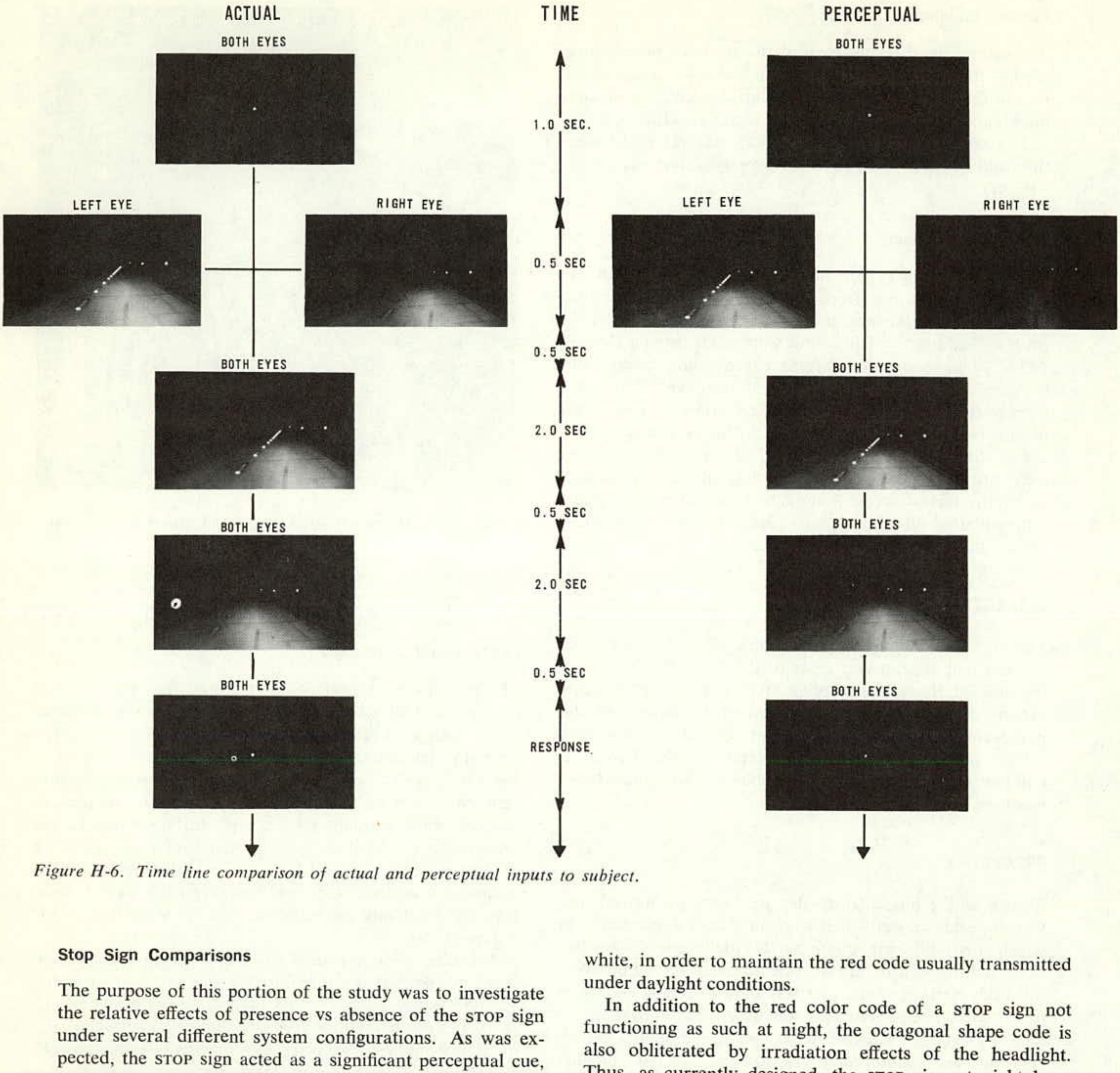

Figure H-6. Time line comparison of actual and perceptual inputs to subject.

Stop Sign Comparisons

The purpose of this portion of the study was to investigate the relative effects of presence vs absence of the STOP sign under several different system configurations. As was expected, the STOP sign acted as a significant perceptual cue, regardless of which system was used (see pairs 1-6). It should be noted that the largest difference resulted when no edge delineation was used (pair 4), because the STOP sign was, in this case, the only edge stimulus provided. The smallest difference existed when the STOP sign was used in conjunction with clear posts as the edge treatment (pair 6). This is quite reasonable, because the STOP sign reflects a white light similar in color and intensity to the clear posts. Thus, the cue loses its distinctiveness in this system. This suggests that if stop approaches are not coded and STOP signs are thus typically used in conjunction with clear post delineators, the reflective coating of the sign should be designed such that the reflective return is red rather than white, in order to maintain the red code usually transmitted under daylight conditions.

In addition to the red color code of a STOP sign not functioning as such at night, the octagonal shape code is also obliterated by irradiation effects of the headlight. Thus, as currently designed, the STOP sign at night loses both the shape and the color code until the vehicle is quite close to the sign. This suggests that the STOP sign could perhaps be made an even more effective cue if these codes could somehow be maintained in the nighttime situation.

Spacing Comparisons

RPM Spacing

It will be recalled that in all cases the RPM's in the stop approach area (i.e., the 720 ft back from the STOP sign) were placed on 40-ft centers. The 40-ft vs 800-ft comparison was made to determine whether or not the transition from 80-ft to 40-ft centers as one proceeded into the stop area would have any significant cue value. In the case of both comparisons (pairs 7 and 8) no significant difference was observed. The fact that no difference was observed does not necessarily mean that both spacings are equally effective. It is possible that in a dynamic situation where the driver had driven a number of miles with 80-ft spacings, the transition to 40 ft would have sufficient "surprise" value to make it an effective cue. However, based on these data the transition does not have the type of "discrete-input" cue value that would be required for the general treatment of stop approaches.

Post Spacing

The direct comparison of post spacing was provided by pair 28. Here it was shown that the geometric spacing provided a more dominant pattern than the conventional (i.e., 200-ft) spacing. The visual effect of the geometric spacing is to create a grouping of delineators near the STOP sign. It will be recalled that the restriction used in the geometric spacing was that no spacing interval would exceed the normal 200-ft interval. Therefore, the intervals from 320 to 1,120 ft are the same as the conventional spacing. Thus, the normal "perspective" effect observed under conventional spacing is enhanced in the geometric spacing to the degree that a distinctive pattern with high attention-getting value results.

Dual vs Single Reference Comparison

The comparisons involving dual vs single references (e.g., posts plus RPM's vs posts *or* RPM's) were made on the basis of the suggestion of several highway engineers interviewed during the current practices survey; i.e., that two lines of delineation would permit the driver to better orient himself spatially. In all cases the dual reference was perceptually more dominant than the single line (see pairs 9-13, 16, 17, 22-24). This result obtained regardless of whether the single line was composed of RPM's or posts, red or clear, and as can be seen in Table H-2 the effect was strong in most cases.

The strength of the two-line system probably lies, at least partially, in the fact that it provides a "tunnel" effect that converges in the area of the STOP sign, thereby providing a strong focal point for the observer. It should be noted that inasmuch as the two-line system would represent, in many cases, an increase in installation cost, a large number of configurations were used to determine whether treatment type or color factors for a single line could override the dual-line effects.

Dual Reference Comparisons

Representative of a controlled comparison of two dual-reference systems are pairs 14, 15, and 25, in which the RPM configuration is the same for each pair element, but the color of the posts is different. No significant difference was observed for pairs 15 and 25. However, counter to this is pair 14, which showed a significantly stronger effect for the RPM plus clear post system as compared to one composed of RPM's plus red posts. The only tenable explanation for this is that pairs 15 and 25 contained a STOP sign in the photograph, whereas pair 14 did not. Given the strength of the STOP sign, it is possible that primary attention was drawn to this cue as opposed to others in pairs 15 and 25, resulting in a large number of response splits between the elements in the pair. In pair 14, where the STOP sign cue did not exist, attention was focused on other cues (viz., color).

Single Reference Comparisons

Treatment Comparisons

The comparisons in this group involved RPM's vs posts (conventional spacing) and RPM's vs posts (#1 spacing), the former represented by pairs 18, 19, 20; the latter, by pair 21. In all cases no significant differences were observed.

Color Comparisons

This group involved clear vs red posts (pair 26) and clear vs red RPM's (pair 27). Rather surprising here is that color was not shown to have significant cue value; i.e., neither pair produced significant differences between the red and clear treatments. Because the subject instructions indicated that the experiment involved a stop approach, it was anticipated that the "red means stop" experience of most drivers would enter into these comparisons to a greater degree than was observed. Inasmuch as a STOP sign was in view in each of the photographs in these pairs, it is possible that the explanation given previously also obtains here; i.e., the overriding attention from other factors, such as color. However, because all well-marked stop approaches have a visible STOP sign, the ineffectiveness of color cues is believed to be relevant. That color does not have a strong perceptual effect is further sup-

Subject Instructions: Perceptual Evaluation Experiment

The purpose of this study is to provide a *perceptual* evaluation of various patterns of delineators or roadway markers that may be used to inform drivers as to when they are coming to a STOP sign.

When you are looking into the viewer on the tachistoscope you will first get a verbal ready signal, shortly after which you will receive a very brief presentation of a roadway photograph. Following this you will receive two successive longer-duration presentations of roadway photographs. Your task is to indicate verbally which of these latter two is the same as the one shown during the brief presentation. Please indicate this by saying "first" or "second" and please refrain from any other comments.

However, if on any given presentation you do not get a picture, please tell the operator. It is essential that you give an answer each time whether or not you are sure of the answer.

Once you are told to look into the viewing hood please stay in that position until you are told by the experimenter to rest. Also, keep both eyes open at all times. During the period of darkness between presentations, but after the verbal ready signal, please focus on the spot of light. You may now look into the viewing hood. Do you see the spot of light? (NOTE: Let subject look into hood until the spot of light is seen—this indicates that dark adaptation is at a sufficient level to begin.) Focus on this and we will run through a trial to familiarize you with everything. Remember, keep both eyes open; do not take your eyes away from the viewing hood until you are told to do so; and do not make any verbal comments other than "first" or "second" unless you do not see a picture on some trial.

Do you have any questions?

Get into position and tell me when you see the spot of light: then we'll begin.

Figure H-7. Instructions to subjects of perceptual evaluation experiment.

ported by the nonsignificant results of the pair 15 and 25 comparisons. In these pairs (which use dual- vs single-line comparisons) the RPM configuration is held constant for each pair but the posts are either clear or red.

Based on the data from this study (admittedly a static situation) one can only conclude that color does not have sufficient cue value to merit the establishment of any new color warrants in the marking of stop approaches.

APPENDIX I

POSITIVE/NEGATIVE DELINEATION *

One of the primary functions of roadway delineation systems is to provide guidance to the driver by informing him of certain critical dimensions in his field of safe travel. The engineer's purpose in patterning the limits of the driver's path, through median (including center and the lane line) and/or edge delineation, is to convey positive information to the driver concerning where he may safely drive. At cross purposes to this intention is (1) the practice of providing (for maintenance crews) markers that serve to locate culverts, drainage ditches, and similar physical features requiring periodic care, and (2) the use of post-mounted reflective devices to mark obstructions and hazards such as bridge piers and abutments. Because all these non-guidance applications tend to involve dangerous obstacles, they typically employ amber reflective devices, which appeal to the driver's cultural bias (viz., yellow or amber implies caution). As such, they can and have been characterized by practicing engineers as *negative* delineation (i.e., they tell the driver where not to drive).

Inasmuch as the need for negative delineation is not independent of the need for positive delineation, both types are often found as part of the same system. One frequently expressed criticism of the combined system is that the net effect of negative delineation is a degradation of the pattern of positive delineation because the negative components fail to convey to the driver the intended message that they mark some type of hazard.

It should be emphasized that the use of negative delineation is not considered *a priori* to be bad. Its contribution to maintenance operations is a prime justification for its widespread use. No such clarity exists as to the role it plays in driver safety, however, because successes, as defined by those occasions in which the driver has processed a negative delineator and has successfully avoided a hazard or obstruction, are rarely reported.

One purpose of this study, then, was to determine the relative effectiveness of positive systems vs combined positive/negative systems. Implicit in this objective is an evaluation of whether or not negative delineators are processed as such and acted upon accordingly. Another related goal was to assess the effect of providing differential visibility between the positive and negative components of the system. The notion here was that if the reflective intensities of negative delineators can be reduced so as to avoid disrupting the positive pattern visible while the driver is still well upstream of the hazardous area, and at the same time maintain a level of intensity sufficient to provide a warning to the driver when he is in the immediate vicinity of the hazard, the best of both purposes will be served.

METHOD

The assessment of negative delineation has proven difficult in the past because there has been no firm basis for comparison; i.e., failures (accidents) are almost always reported and available, whereas little is known regarding successes (avoiding accidents). In the absence of such exposure data, failure frequencies are meaningless. This experiment was designed to obtain the necessary "rate" information without influencing the subject's normal attention to delineation in any way. This was accomplished by providing a cover story that deliberately misled the subject as to the purpose of the study.

The underlying assumption in the design of this experiment was that the success/exposure ratio information would be meaningful only to the extent that the test simulated a real-world hazard. Thus, a controlled field study was designed in which a hazardous event was programmed that forced the subject to take evasive action by actually leaving the road abruptly in the vicinity of still another hazard. This second hazard was a simulated obstruction delineated differentially according to a preconceived experimental design. Driver reactions to the second hazard were the dependent variables of interest.

Procedure

The "reaction-time" cover story and instructions given to each subject upon his arrival at the test site were as shown in Figure I-1.

The test site was a closed section of Route 220 between Mt. Eagle and Howard, Pa. The roadway was a two-lane two-way facility with 12-ft lanes and hard shoulders. The

* By Edmond L. Seguin and Robert S. Hostetter, Senior Research Associate, and David Tait, Research Assistant, Institute for Research, State College, Pa.

surface was asphaltic and the over-all condition of the roadway was good. The right shoulder of a 2-mile section was delineated with clear post delineators on 200-ft centers. This pattern was interrupted at two target areas by placing four additional posts, which varied in intensity and/or color (according to the experimental design) on 20-ft centers.

The target-area delineation conditions that constituted the primary independent variables of the study were: (A) no delineation; (B) amber post delineators; (C) filtered (low intensity) amber post delineators; (D) filtered (low intensity) clear delineators.

Two target areas were used in order to minimize the subjects' use of distance traveled, landmarks, or other cues that might have resulted in anticipatory responses. To further prevent or minimize one-trial learning (i.e., anticipation of the stimulus upon seeing an oncoming vehicle as a result of the first run), a decoy vehicle was used in addition to the experimenter's van. On a given run, the positions of the decoy and the van were determined by consulting the experimental design.

The design used was a Graeco-Latin square partially balanced for residual effects. Each of 24 subjects had one trial on each of the four treatment conditions (the primary independent variables previously noted). The target area and the position of the decoy vehicle were balanced by arranging them in a 2×2 format and coding the cells 1 through 4 as shown in Figure I-2. These codes were used in conjunction with the treatment condition designates A, B, C, and D to arrive at the final design given in Table I-1.

Subjects

Of the 24 subjects, 14 were male and 10 were female. The average driving experience for the male subjects was 11.1 years; for the females, 10.6 years. The range across the total sample was from 2 to 22 years. The mean annual mileage driven was approximately 12,000, with a range from 2,000 to 25,000.

Instructions for Positive/Negative Delineation Experiment

The purpose of the study in which you are about to participate is to obtain basic data on driver decision and reaction time under emergency conditions. Because we cannot expose people to actual danger requiring such emergency action, we are using a simulated situation. The emergency we are simulating is the late initiation of a pass by a vehicle coming toward you.

We want you to drive down the roadway at a constant speed of 35 mph. At some point you will see highlights in the opposing lane. At a later point another set of headlights will appear in your lane beside the other opposing vehicle. *The appearance of headlights in your lane is your signal to react.* As soon as you see them your task is to get your vehicle off the roadway as quickly as possible without losing control. Although all vehicles in the oncoming lane will be involved in the experiment, not all will be the vehicle to which you will have to react; that is, the headlights of the simulated passing vehicle may or may not appear.

Remember, we do not want you to slow down or pull off the roadway until you see two adjacent pairs of headlights coming in your direction. The reaction time measure in which we are interested begins when the two sets of headlights appear beside each other and ends when your vehicle is entirely stopped and entirely off the roadway. Please keep in mind that the passing situation is simulated and therefore there is no need to panic. Just react as quickly as you can while taking care to maintain control.

When you first get into the car please adjust the seat position and lap and shoulder belts so that you are comfortable. When you start, accelerate to 35 mph fairly quickly, and maintain that speed throughout the run. Once you have completed the trial and have the vehicle pulled off the roadway, remain there until the experimenter at the other end of the site gives you further instructions.

In order to obtain reliable reaction time estimates, you will make several runs.

Do you have any questions?

The car has power steering and an automatic transmission but it does *not* have power brakes. You may now get into the car, get everything adjusted and drive up the road for about a quarter of a mile, during which you can try the brakes several times and get some idea as to the steering and handling characteristics. Then return here and I will tell you when to begin your first run.

Figure I-1. Reaction-time cover story and instructions for positive/negative delineation experiment.

TARGET AREA	CELL NUMBER FOR POSITION OF DECOY: FIRST	SECOND
Near	1	2
Far	3	4

Figure I-2. Coded decoy position and target area.

TABLE I-1

EXPERIMENTAL DESIGN

SUB. NO.	TREATMENT CONDITION FOR TRIAL NUMBER 1	2	3	4	SUB. NO.	TREATMENT CONDITION FOR TRIAL NUMBER 1	2	3	4
1	A1	B2	C3	D4	13	A1	B2	D3	C4
2	A3	C4	B1	D2	14	A1	C2	D3	B4
3	A4	D3	B2	C1	15	A3	D4	C1	B2
4	B3	A4	C1	D2	16	B3	A4	D1	C2
5	B1	C2	A3	D4	17	B4	C3	D2	A1
6	B2	D1	A4	C3	18	B2	D1	C4	A3
7	C3	A4	B1	D2	19	C1	A2	D3	B4
8	C2	B1	A4	D3	20	C3	B4	D1	A2
9	C4	D3	A2	B1	21	C2	D1	B4	A3
10	D1	A2	B3	C4	22	D2	A1	C4	B3
11	D4	B3	A2	C1	23	D4	B3	C2	A1
12	D4	C3	A2	B1	24	D2	C1	B4	A3

In addition to the performance data collected, each subject was interviewed after making all four runs. The questionnaire used for these data is shown in Appendix U.

Apparatus

The equipment used in this study can best be described in the context of its use and deployment for any given trial run. Figure I-3 shows a schematic arrangement of all components prepared to conduct a test run under any treatment condition involving a code 3.

(a) *Passing vehicle simulator:* The device shown in Figure I-4 was developed to simulate realistically an oncoming vehicle engaged in an improper passing maneuver at night, without endangering the drivers and/or vehicles involved.

The simulator consisted of a two-by-four wooden frame 10 ft long and 18 in. high painted a flat black to eliminate reflections. It was side-mounted to the trailer hitch of a van (experimenter vehicle) so that it could pivot easily in the event of a collision with the subject vehicle (fortunately this feature was never tested during the study). The far end of the simulator was supported by a tandem bicycle wheel assembly, which was light, easy to maneuver, and again offered little in the way of resistance should it have been hit by a subject vehicle. The simulator was towed and held at right angles to the experimenter vehicle by a thin nylon cord extending from the wheel assembly to the front bumper of the van. The cord was secured to the bumper with a slip knot, making break-away easy had it become necessary. The headlights used in the simulator were conventional sealed-beam lamps mounted along the top beam of the simulator. The height (26 in.) and distance between units (50 in.) were representative of measurements taken on a sample of modern vehicles. The simulator lamps were wired to the 12-v system of the experimenter vehicle and controlled through a switch mounted on the front seat.

(b) *Vehicles:* Three vehicles were used for each run: the experimenter's 1968 Chevrolet van (with attached simulator); the decoy vehicle, a 1969 Volvo station wagon; and the subject vehicle, a 1970 Plymouth sedan equipped with power steering and automatic transmission.

(c) *Communications:* Three Messenger 200 mobile radio units were used to provide the necessary communications links between the dispatching station at the head of the site and the experimenter and decoy vehicles.

(d) *Triggers and reference marks:* The ready signal shown in Figure I-3 was triggered by the passage of the subject vehicle and was used to signal the driver of the van to move toward the target area. Reference posts were installed to enable the van driver to control his speed such that he arrived at the same point (on repeated runs) when the subject vehicle activated the stimulus trigger. When the stimulus trigger was activated, the driver of the van immediately switched on the lights of the passing vehicle simulator. Given the speeds and distances involved, the subject driver's path of evasive action carried him into the target area. The trigger systems employed pneumatic tubes placed across the roadway at fixed distances upstream of each target area. The tubes were linked to Junior traffic counters, which were wired as switches for 16-v light systems. These lights were mounted on 4-ft posts and were concealed by means of 3 × 6-in. directional cylinders placed in front of the lens. The traffic counters, batteries, posts, and light assemblies were all painted flat black and positioned off the shoulder so as to be visible to the experimenter and, at the same time, be virtually undetectable

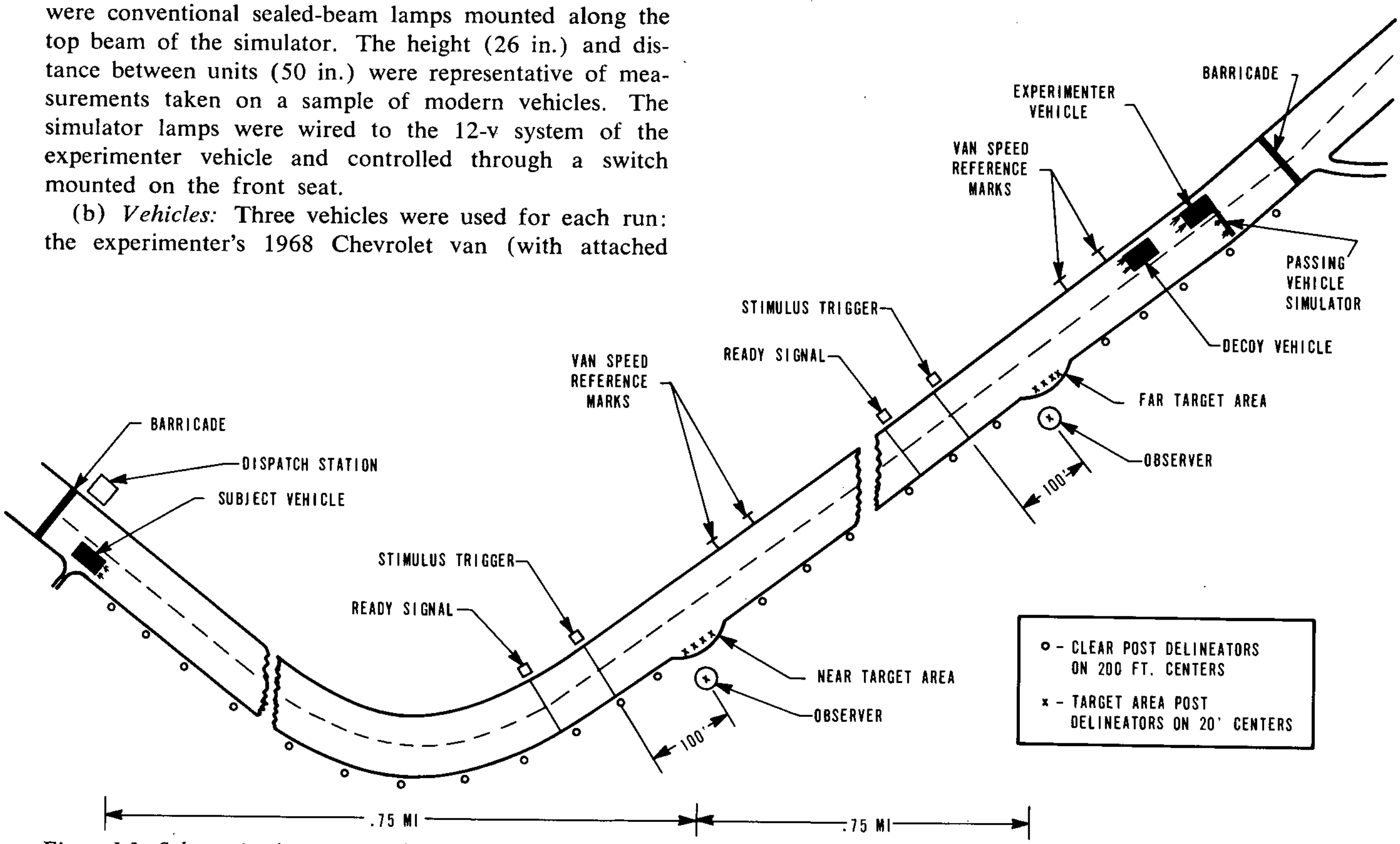

Figure I-3. Schematic of test site used for positive/negative vs positive study.

Figure I-4. Passing vehicle simulator.

by the subjects either on a test run or on the return trip.

(e) *Observers:* A hidden observer was positioned at a vantage point upstream and off the subject's side of the road, giving him adequate protection and at the same time an excellent view of the target area. As soon as the subject vehicle had altered its path the observer noted the point where the right front tire crossed the edge of the pavement. The driver of the decoy vehicle and the observer, using a 100-ft steel tape, then measured the "off-the-road" distance, using as a reference point the first post in the target area. They then measured the distance to the front of the subject vehicle after the completed stop and instructed the subject to return to the dispatch point. The number and position of knocked-down posts were noted, together with any other observations peculiar to that particular run. The posts were then set up for the next experimental condition at that target area and the next run began.

RESULTS AND DISCUSSION

In general, the results of the road tests do not suggest any differential effectiveness between the positive-only and the positive/negative systems. The primary measure used to assess effectiveness was the number of delineation posts struck. It was hypothesized that if drivers knew the meaning of the negative delineators, fewer delineator posts would be hit under condition C than under condition D. The no-delineation condition (A), used only the black posts with no reflectors on them as a base line condition against which the other treatments were evaluated. Moreover, if reduction in intensity (the differential visibility aspect) produces a negative effect on performance, one would expect more hits under the amber-filtered condition (C) than under the amber-unfiltered condition (B).

Inasmuch as each subject was exposed to each condition, the chi-square test for correlated proportions was used to analyze the hit frequency data. In this test only discordant cases are involved; i.e., data are classified for two conditions (e.g., A and B) simultaneously as HIT-A/HIT-B, MISS-A/HIT-B, HIT-A/MISS-B, MISS-A/MISS-B. Only the MISS-A/HIT-B, and HIT-A/MISS-B data are employed in the χ^2 test for correlated proportions. Because the cell frequencies were small, the Yates correction for continuity was incorporated into the test. Because of the contingency involved in classifying the data, the χ^2 values do not show a one-to-one correspondence with the raw percentage of hits observed for each condition. Table I-2 summarizes performance on the road under each of the treatment conditions.

The crucial performance measurement is, of course, the percentage of subjects who hit delineator posts under the various conditions. As expected, condition A (no delineation) resulted in the highest raw percentage of hits. However, the only performance difference that is significant at the 0.05 level using the χ^2 test for correlated proportions is that between the no-delineation condition (A) and the clear-filtered condition (D)—a χ^2 value of 4.16. The differences between conditions A and B, and A and C have chance expectancies of approximately 0.20, with χ^2 values of 2.50 and 1.76, respectively. All other comparisons were nonsignificant. Given that the only significant difference is between the no-delineation and the clear post conditions, these data would indicate that the use of amber for marking hazards or obstructions is superfluous from the driver's standpoint. In other words, under the emergency-type con-

TABLE I-2

ROAD TEST PERFORMANCE SUMMARY

DELINEATION CONDITION	SUBJECTS HITTING POSTS (%)	MEAN DIST. TRAVELED[a] BEFORE LEAVING ROADWAY (FT)	MEAN STOPPING DISTANCE (FT)	SUBJECTS FULLY LEAVING ROADWAY (%)
A	58	33.6	86.4	71
B	33	43.8	90.8	58
C	38	41.7	89.4	67
D	33	45.9	92.8	58

[a] Beyond No. 1 target post.

TABLE I-3

SUMMARY OF RESULTS OF POST-EXPERIMENTAL INTERVIEW

QUESTION	RESULTS
3. Change in size of reflectors?	Yes, 12.5%; No, 87.5%
4. Change in brightness?	Yes, 25.0%; No, 75.0%
5. Color differences?	Yes, 45.8% [a]; No, 54.2%
6. Meaning of amber? [b]	No meaning, 37.5% Bridge, 8.3% Edge of road, 16.7% Curve, 16.7% Caution, 45.8% [c]
7. Confusion due to amber?	Yes, 33.3%; No, 66.7%
8. Ever involved in off-road emergency?	Yes, 37.5% [d]; No, 62.5%

[a] Color changes noticed (some subjects reported more than one change): Clear to yellow, 5; clear to orange, 3; clear to red, 3; clear to amber, 1.
[b] Some subjects gave more than one meaning.
[c] Of those responding "Caution," specific items noted were one each of hazard, ditch, island, curve; two each of obstruction, driveway.
[d] Six subjects specified reason as avoidance of a head-on collision.

ditions simulated in this study, drivers were as likely to hit an obstruction when the hazard was delineated with amber reflectors as they were when it was unmarked.

With respect to the effect of reducing the intensity of negative delineators in order to reduce the potential clutter problem, the data indicate that intensity reduction does not reliably influence performance. However, the raw percentage difference between the amber filtered (C) and amber unfiltered (B) condition, when considered alone, is in a direction that would suggest that intensity reduction may have a negative effect on avoidance responses. Because no such differences were observed between the high-intensity amber (B) and the low-intensity clear (D), however, one is forced to acknowledge either a color advantage for clear (C vs D) or that reducing the intensity has little effect. In light of the finding in the overdelineation study that little or no control is exerted on speed behavior through reducing reflective intensity, the safer inference appears to be that differential visibility can be provided at no cost in performance.

The results of the interviews conducted at the end of the four trial sessions are presented in Table I-3. These data provide some insight as to why the subjects tended to perform poorly in terms of avoiding the second hazard when it was properly delineated. Only 45.8 percent of the subjects knew that amber implied a hazard; yet 66.7 percent reported that they were never confused by the presence of amber. To be representative of the general driving population, these findings represent a dangerously inadequate knowledge of roadway codes. Moreover, the state of ignorance and/or confusion is compounded by the failure to detect and/or discriminate color stimuli, as evidenced by the fact that more than one-half (54.2 percent) of the subjects failed to notice any color, even though they drove a collision course at amber delineators on two of their four trials. It would appear that if a reasonable performance effectiveness judgment is to be made regarding any roadway system elements the engineer's intention in providing that element must be communicated to the driving public.

In light of the rather astonishing report that 37.5 percent of the sample had experienced an actual emergency that required them to leave the road, it would be premature to judge negative delineation as ineffective. Rather, serious and immediate attention should be given to informing the driver of the meaning of codes, either as a requirement of the licensing procedure or through public service information campaigns via the communications media, or both. Furthermore, the self-reported failures in visual effectiveness shown for color and intensity suggest a need for (a) a method of enhancing the detectability and discriminability of existing visual codes and devices and/or (b) a development of new and better display alternatives.

APPENDIX J

EVALUATION OF THE VISIBILITY OF REFLECTIVE DEVICES *

A straightforward statement of the visibility of a given device is not easily accomplished. Although physical relationships of any device can be specified and measured, there are so many variables in a given application that it soon becomes necessary to make many approximations for a practical determination. Some of these variables are discussed, and useful generalities are formulated. The translation of this information into practical decisions, it is hoped, will be aided by this discussion, but it remains necessary to employ a great deal of engineering judgment. Because so much information is available from previously performed studies, no addition field evaluations were made under this task.

Light represents one portion of the electromagnetic spectrum; therefore, it can be measured in the same radiometric units as other forms of energy such as heat, microwaves, and electrical energy. In any application that does not involve human vision it is appropriate to use *radiant* † units.

In contrast to radiant units, *photometric* or *luminous* light units are used when the light energy being considered is that energy to which the human eye is sensitive. Luminous standards, therefore, should be used only in applications related to human vision. The spectral range of luminous light covers the wavelength region from about 400 to 720 nanometers (nm ‡ or meters $\times 10^{-9}$). Luminous units are units of light within this spectral region that will produce equal effects on a standard (average normal adult) observer. In other words, it may take 15 times as much energy (radiometric units of power, or watts) of pure red light to appear as bright as one unit of yellow light, but photometric units compensate for this different spectral sensitivity of the eye, so that one luminous unit (or *lumen*) of any color light appears as bright as one luminous unit of any other color.

Although the eye is much less sensitive to a pure red light than to pure yellow (Table J-1), practical devices seldom employ pure colors. The "red" reflector is far from a pure red color. The light reflected is predominately white § light with a comparatively small amount of red light added. Thus, a practical reflecting device that appears yellow may be only about two times as bright in appearance as a similar device that appears red when both devices are illuminated by the same source.

* By Richard A. Olsen, Research Assistant, The Pennsylvania State University.

† The basic or preferred units and terms are italicized where they first appear.

‡ Obsolete units are millimicron ($m\mu$) $= 10^{-9}$ m and Angstrom (A) $=$ 10^{-10} m.

§ Light that looks white is a mixture of at least three frequencies, usually many more. Color in nature is seldom the product of a single frequency but results from particular mixtures of frequencies present and their relative intensities.

COMMON UNITS IN VISIBILITY

A source such as a headlight emits light in one general direction using a focused beam, with decreasing amounts as the direction varies. The *intensity* of a source is measured in *candelas* and determines the *luminous flux* in a given direction (lumens per solid angle). At a particular point of observation, the intensity yields a number of *candelas* (or candles or candlepower), and *isocandle charts* are available for various sources for describing the intensity of the light at any position. For example, a GE-4002 lower-beam headlamp projects a flat oval of light with a narrow pencil beam in the center that has an intensity of about 21,000 candelas. As the angle is changed, the intensity drops sharply. At about 5° off the central axis, the intensity is only 5,000 candelas; and at 6° up, 12° down, or 25° left or right, the intensity is reduced to about 250 candelas. This illustrates the desirability of having reflective devices mounted slightly below headlight height and fairly close to the lane of travel.

In the presence of a light source a surface or reflector becomes illuminated. The *illuminance* of a spot on a surface is related to the intensity of the source beam in that direction and the distance between the source and the spot. Illuminance is commonly expressed as candelas (cd) per distance squared, or *footcandles;* i.e., fc $=$ cd/ft^2.

Another unit of illuminance similar to the footcandle is expressed as lumens * per square foot (lm/ft^2), which, for a surface (not focused) source, is equal to π times the source intensity in candelas. Other units are also used, with the *lumen per meter squared* (lm/m^2) as the recommended (but not yet common) standard. It is also called the *lux* or the meter-candle, and fc $\times$ 10.764 gives the number of lm/m^2, or lux. A sunny winter day may provide a level of more than 100,000 fc on the snow, but large print can be read with only about 1 fc.

When a surface illuminated by a source is observed, the observer perceives a photometric or surface brightness that is called *luminance*. A surface can be considered a "source" (of reflected light), but intensity is used with small sources; luminance, with surfaces. This luminance or surface brightness is expressed as the intensity over the area of the surface in *candelas per square foot* (cd/ft^2). This has the same dimensions as the footcandle (cd/ft^2), but the *area* of the surface, rather than the *distance squared,* appears in the denominator. The preferred unit of luminance is to become *candelas per square meter* (cd/m^2), which is obtained by multiplying cd/ft^2 $\times$ 10.764. The foot-Lambert (fL) is a common (smaller) alternative and fL $\times$ 3.4263 gives cd/m^2.

* One lumen of greenish-yellow light is about 1.46 milliwatts of power. If all of this power were beamed into an area of 1 ft^2 at a distance of 1 ft from the source, the intensity of the source would be 1 candela (or 1 candle, or 1 candlepower).

The brightness of a reflective surface depends on the optical qualities of that surface. In order to compare reflectors, a relative measure of reflecting efficiency is needed. The *specific intensity* (SI) is a measure of the intensity of a reflecting surface for a given amount of illumination and a given point of observation; that is,

$$\mathrm{SI} = \frac{\text{Intensity of projected area}}{\text{Illuminance on projected area}} (\mathrm{cd/fc}) \qquad \text{(J-1)}$$

The size of the surface is not considered. However, both measures are made from some angle of observation, but necessarily perpendicular to the surface.

When the size of the surface is considered, the relative luminance of a reflector or the *specific luminance* (SL) is used.

$$\mathrm{SL} = \frac{\text{Luminance of projected area}}{\text{Illuminance on projected area}} \left(\frac{\mathrm{cd/area}}{\mathrm{cd/distance^2}} \right) \qquad \text{(J-2)}$$

for units of $\left(\frac{\mathrm{cd/ft^2}}{\mathrm{fc}}\right)$ or $\left(\frac{\mathrm{fL}}{\mathrm{fc}}\right)$*.

Another unit is used that appears to be equivalent to SL, but which has a distinct difference. This is the *cd/fc/ft²*.

Figure J-1 relates the physical reflector and the area of the reflector projected for a point A at some *entrance angle*. SI and SL are concerned with measures taken at A for the effective area. Both illuminating source and observer are at A. In the photometry of reflectors a convention developed of measuring luminance ($\mathrm{cd/ft^2}$) at the place where the reflector would be, using the actual area of the reflector, which is larger in a direction normal to the reflector (seen from B) than from some other position (e.g., point A). Although source and observer are usually at very nearly the same angle where highway delineation is concerned, this small difference, the divergence angle, is important; it is discussed later. The unit ($\mathrm{cd/fc/ft^2}$) is convenient in some calculations because the same physical area of the reflector sample is used, regardless of entrance angle being considered. For this reason it is called the *sample specific luminance* (SSL)† to distinguish it from the SL. Thus, a smaller value results for SSL when the larger area is used as a divisor in calculating luminance: that is,

* Divide fL by π to get ($\mathrm{cd/ft^2}$). Some photometers measure surface luminance directly in foot-Lamberts.

† Often not named, being referred to only as "cd/fc/ft²"; may be called "specific brightness," although this is sometimes in cd/fc/in².

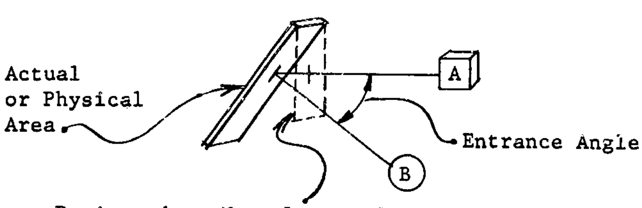

Figure J-1. Photometric relationships.

$$\frac{\text{Luminance of physical area } (\mathrm{cd/ft^2})}{\text{Illuminance of projected area (fc)}} = (\mathrm{cd/fc/ft^2}) = \mathrm{SSL} \qquad \text{(J-3)}$$

and

$$\mathrm{SL}\left(\frac{\mathrm{cd/ft^2}}{\mathrm{fc}}\right) \times \cos\,(\text{entrance angle}) = \mathrm{SSL}(\mathrm{cd/fc/ft^2}) \qquad \text{(J-4)}$$

This cosine factor can often be ignored without serious error when the entrance angle is not large: $\cos 20° = 0.940$ and $\cos 30° = 0.866$, so that SSL would be only 6 percent and 13 percent smaller than SL, respectively.

1. To calculate the luminance of a reflective material:
   (a) Measure SSL or SL at particular entrance angle (EA) of interest or, if SI is given, divide SI by reflective area in square feet to get SSL.
   (b) If necessary, convert: Divide SSL($\mathrm{cd/fc/ft^2}$) by cos (EA) to get SL $\left(\frac{\mathrm{cd/ft^2}}{\mathrm{fc}}\right)$.
   (c) Read isocandle chart or measure intensity in candelas of source in direction of reflector. Convert: divide candelas by the distance (D) in ft, squared, to get illuminance of reflector, E. (If more than one source, calculate each and add for total illuminance.)

$$E(\mathrm{fc}) = \frac{\text{candelas}}{D^2}\left(\frac{\mathrm{cd}}{\mathrm{ft^2}}\right) \text{or (fc)} \qquad \text{(J-5)}$$

2. Luminance of reflector:

$$L(\mathrm{fc}) = \mathrm{SL}\left(\frac{\mathrm{cd/ft^2}}{\mathrm{fc}}\right) \times E(\mathrm{fc}) \qquad \text{(J-6)}$$

   To express in other units: fc is equivalent to $\mathrm{cd/ft^2}$; multiply fc by 10.764 to get lumens/m² or lux; multiply fc by π to get fL.*

3. Intensity of the returned light (I_R) is the luminance of the reflector (L) times the reflecting area (A):

$$I_R(\mathrm{cd}) = L(\mathrm{cd/ft^2}) \times A(\mathrm{ft^2})$$
$$= \frac{1}{\pi} L(\mathrm{fL}) \times A(\mathrm{ft^2}) \qquad \text{(J-7)}$$

4. Illuminance (in clear air) at the observing eye (E_{eye}) then depends on the distance (D) from the reflector.

$$E_{\mathrm{eye}}(\mathrm{fc}) = \frac{I_R(\mathrm{cd})}{D^2(\mathrm{ft^2})} \qquad \text{(J-8)}$$

5. *Visibility* (the ability of an average observer to *detect* the reflector's presence) is assumed if the *illuminance at the eye* is above some *threshold* value. The appropriate threshold varies for individual observers, not only because of visual capabilities but also depending on whether the observer expects to

* The usual unit for luminance is fL to distinguish (cd/area) from the fc, which is (cd/distance²), for illuminance.

see something, what he expects, and where he expects it to appear.

A commonly used threshold is 0.5 *mile-candle.* This is

$$0.5\text{cd/mi.}^2 \quad \text{or} \quad 0.5\text{cd/(5,280ft)}^2 \quad \text{or} \quad 1.8 \times 10^{-8}\text{fc.}$$

Cook (*68*) used 3×10^{-7} fc as a threshold, which proved to be somewhat high compared to his field detection data where lower illuminance was detected. If the reflector is intended to attract attention (i.e., it is not expected), the illuminance will have to be much higher, perhaps 1,000 times or about 10^{-5} fc. For convenience, *a threshold of 10^{-7} fc illuminance at the eye* is probably reasonably realistic for delineators.

Illustrative Example

Cook (*68*) provided curves for a beaded material and a corner cube reflector in terms of SSL for a range of divergence angles and several entrance angles (Fig. J-2). These values, however, are only representative of the types of materials. For example, other sheeting would plot between the two sets of curves shown. The encapsulated lens sheeting would rival closely the corner cube values plotted. Figure J-3 shows the illuminance at the eye as a function of distance. Because illuminance changes in proportion to reflector area, it can be seen that, at shorter ranges, relatively large reductions (about 100 or 1,000 to 1) in area or reflectance are necessary before the illuminance approaches the threshold. These figures are discussed further in a later section.

VARIABLES IN VISUAL DETECTION

The visibility of an object depends on several factors (*68*), including its size, its shape, the viewing angle, the distance to the observer, the recent exposure of his eyes, the distribution of color and brightness on the surface, the type and beam pattern of light illuminating the object, the background, and the transmission characteristics of the atmosphere. Most of these factors vary widely in any practical situation involving a driver and an object in the vicinity. Whereas an ordinary dark surface may reflect less than one-tenth of the incident light, a clean white surface may reflect more than three-fourths of the light. An untreated surface reflects light in essentially all directions away from it. In contrast, a reflex (corner-cube or glass-beaded) reflector may return up to 1,000 times more light concentrated in the direction of the illuminating source. For example, a clean, white-painted license plate can be seen at 250 ft, but a reflectorized license plate can be seen up to 1,000 ft (*68*).

In discussing the effectiveness of various reflectors, it is necessary to make a distinction between pattern recognition and detection. Although reflectorization of signs and symbols is useful, delineation is concerned more directly with the detection of individual reflective units. The delineation intended in any reflective system will not usually depend on single units, but rather on patterns of units.

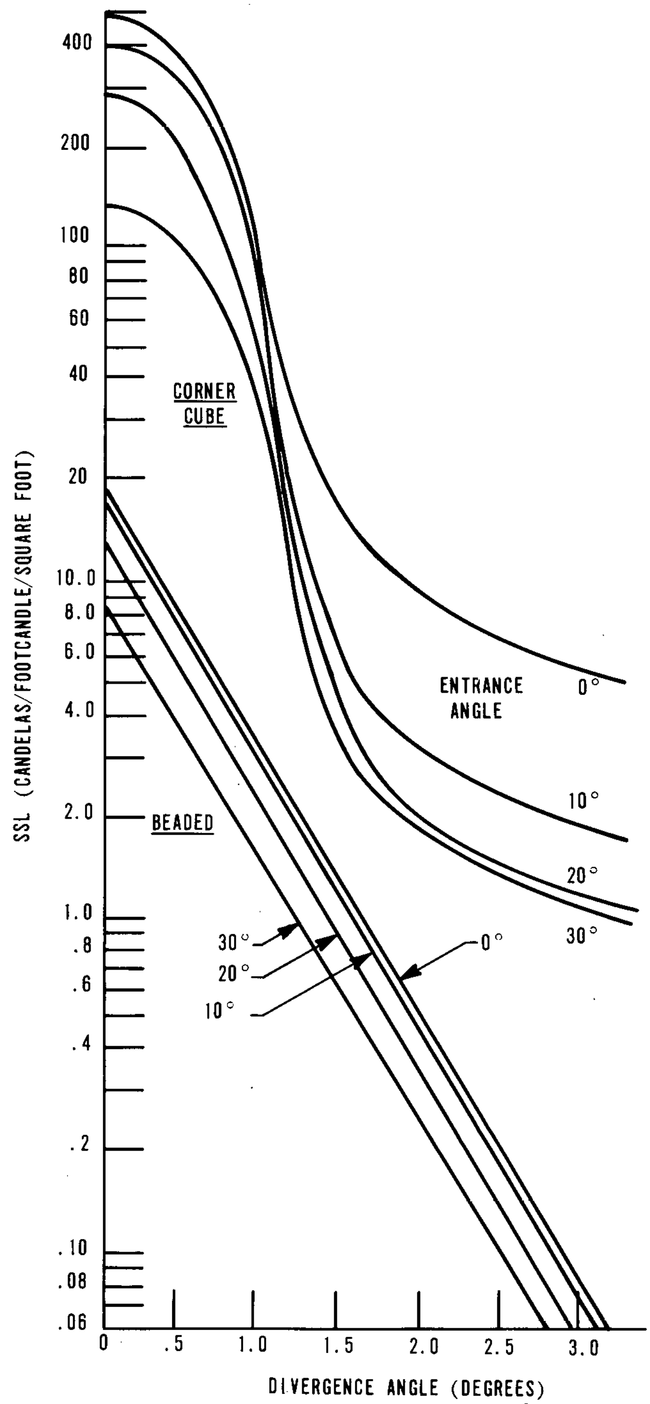

Figure J-2. Sample specific luminance (cd/fc/ft²) for a red corner-cube reflector and a red beaded sheeting conforming to Federal Specification L-S-300. (Adapted from Cook, 68; *data from Stimsonite Division of ESNA and 3M Corp.)*

Inasmuch as three or more points determine a line or curve, a driver is given some knowledge of the course of a road if he can see three bright points. Although it is conceivable for a driver to track individual bright points one at a time in a very dense fog, it is commonly accepted (*41*) that three units should be visible where delineation is used, regardless of vertical and horizontal curvature.

In one study of edge delineation (*41*), the night traffic speeds tended to increase more when shoulder stripe delineation was added than when post delineators were installed. The continuous guidance effect provided by a line removes any requirement on the driver for interpreting or "linking" the markings. Closer spacing of post-mounted units could also approach continuous guidance.

There is still considerable controversy over the maximum desirable distance at which a reflector should be visible. Rockwell (*378*) has concluded from eye-movement studies that driver behavior does not change when delineation is provided beyond approximately 100 ft ahead. The stopping dinstance from 50 mph is approximately 150 ft. If this is considered the absolute minimum for providing some advance delineation information, presumably drivers would perform quite well if they could reliably detect a delineator at 150 ft or more. There is a possibility that drivers may become confused by too much advance delineation, especially where S-curves that lie immediately ahead are not visible and the delineators on curves farther ahead are visible. There is also the "fascination" effect of many discrete, bright points streaming past a driver in a continuous succession. Because the task at hand is related to estimates of visibility distances, these latter factors are not discussed further.

Although laboratory and analytic studies are designed to provide precision with highly controlled variables, this strict control often makes it difficult to extend the conclusions to practical situations. On the other hand, field observations of actual installations are more "realistic," but the variations encountered in practical situations are so great that no small sample can be considered completely generalizable.

A great deal is known about the variables affecting the detection of objects and, given enough information, it is possible to use mathematical techniques for predicting when an object will be visible. Thus, field tests are useful in validating analytical techniques, but neither method can be said to be completely "realistic" for practical decision making. In either case, whether field tests or laboratory tests are used to evaluate reflective devices, careful con-

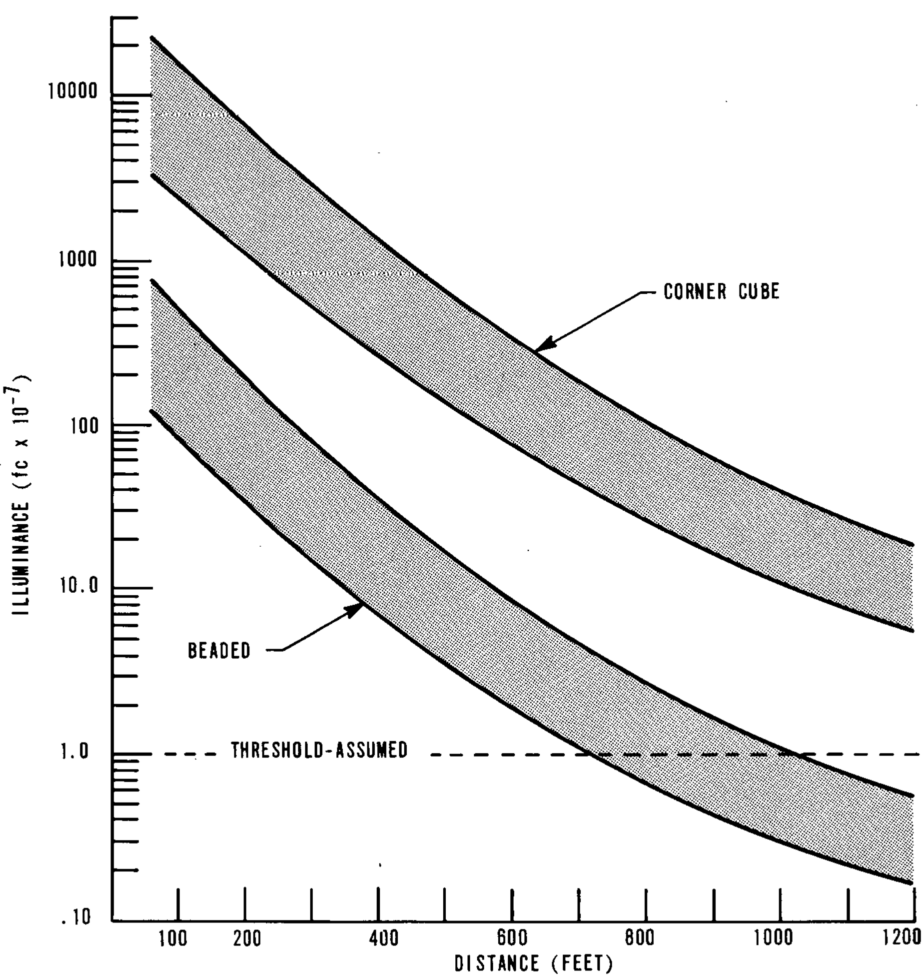

Figure J-3. Range of illuminance at the eye ($fc \times 10^{-7}$) produced by one square foot of beaded and corner-cube reflector material; low beam, 0° entrance angle, no vertical displacement, horizontal displacement varied from 8 ft left to 22 ft right of right headlight. (Adapted from Cook, 68.)

sideration must be given to control of the relevant variables and to measurement of a realistic criterion.

Field observations are necessary when uncontrollable variables are present. The delineation of a road edge is straightforward enough that all variables can be measured, even if this becomes a cumbersome task. Laboratory tests that attempt to compare one device to another do so in a precise fashion; but, because devices are often mounted in different ways, at different locations and spacings, and for different purposes, such a comparison loses predictive value. The problem of comparing various commercially produced devices is made much more difficult by the tremendous variety of methods and units (many missing, some inappropriate) used in literature describing the performance of various devices.

TABLE J-1

COLOR AND REFLECTIVE SENSITIVITY OF THE EYE FOR SINGLE WAVELENGTHS OF LIGHT FOR A NORMAL (TRICHROMATIC) OBSERVER

COLOR	WAVELENGTH (NM)	WATTS/LUMEN
Violet	397	4.3
Indigo	424	0.23
Blue	455	0.30
Green	492	0.0063
Yellow	575	0.0016
Orange	585	0.0018
Red	647	0.012
	723	1.7

The Variables

A brief discussion of the variables important to visibility follows. A detailed discussion of these points can be found in Cook (*68*); the summary here is meant only to indicate the sources of difficulty.

Reflector Size

A small reflector at a distance can be considered a "point source" so that its visibility depends on its intensity and the distance. When a source is large, visibility is determined by the intensity per unit area or luminance and it will appear equally bright regardless of distance (in clear air) because the change in the visual area exactly compensates for the change due to distance (when illumination is constant).

A reflector can be made to appear brighter by making it larger, so long as it does not exceed the maximum size for a point source. Because this maximum size is determined by the background illumination, which controls the size of the entrance pupil and the adaptation state of the eye, it is not a fixed value. A disc up to 3 in. in diameter can be considered a point source at dusk beyond 375 ft. At shorter distances the reflector becomes an extended source and apparent brightness is independent of the distance of the observer. During a moonless overcast night, the same 3-in. disc would act as a point source beyond only about 70 ft. Thus, when the requirement for delineation is greatest (on a very dark night) a 3-in. delineator would become more and more visible as distance decreased down to about 70 ft. From then on the visibility would no longer increase and give cues for distance. At dusk, the delineator would tend to appear equal in brightness from 375 ft and closer. Inasmuch as headlight illuminance is highly directional, these relationships are only approximate. However, the lack of distance cue at intermediate distances can be confusing to drivers.

Location of the Elements

Because reflectors are not light sources, the apparent intensity of a reflector depends on distance and the beam pattern of the light incident on it, as well as on the angles between the incident light, the surface, and the observing eye.

The *divergence angle* (or angle of deviation) is the angle at the reflector position between the observer's eye and the light source.

The *entrance angle* (or incidence angle) is the angle between the light source and a line normal to the reflector surface.

The *orientation angle* (rotation angle) is related to rotation of the reflecting unit in its own plane or the plane normal to the line of observation.

Because the corner-cube reflector returns incident light almost parallel to its original path, the narrow cone of reflected light may not include the eye of the driver at close ranges. The dispersion of light by a corner-cube reflector may be so small that the amount of light returned in the direction of the observer's eye is below his detection threshold. It is possible to design corner-cube reflectors with wider dispersion angles, but the brightness is then reduced throughout the solid angle of the reflected light because the same amount of energy is spread over a larger area.

Type and Condition of the Reflector

Different types and brands of reflectors vary widely in their characteristics. There may even be considerable variation among individual units within the same production lot. The physical condition influenced by aging, weathering, moisture, dirt, or chemical effects can make drastic changes in reflectance. Because visibility is closely related to a logarithmic function of illuminance at the eye, a reflector that is reduced to 30 percent, or even 10 percent, of its original reflectance may still be quite serviceable. The SL and SSL of a reflector are measures of its brightness for a given illumination and a given size to permit comparison of different sizes and types of reflectors.

Atmospheric Transmissivity

Precipitation, particulate matter, and fog may reduce the transparency or increase the dispersion of the atmosphere.

Although a reflector may be visible at 30 ft even in thick fog, it may not be visible in a thinner fog at 300 ft.

Light Source

It is meaningless to discuss the power of a light source in discussing visibility. The beam pattern of a headlight is carefully formed to provide light where it most likely to be useful to the driver and very little elsewhere. Inasmuch as a reflector can reflect only the light that falls on it, the visibility of the reflector depends on the part of the beam pattern that illuminates it. There are variations in beam patterns among individual units, as well as differences with age, aiming, vehicle loading, number of lights, supply voltage, and temperature.

Although there is some variation in the physical location of headlights and driver eye positions from model to model and from driver to driver, reasonable average values can be determined for the automobile driving population. Cook (*68*) has provided detailed procedures for calculating the angular relationships between lights, reflectors, and observers. The procedure is straightforward and detailed worksheets are provided; but the task remains a tedious, complicated one. For late-model cars the headlamp is approximately 2.5 ft above the pavement and the driver's eyes are approximately 1.6 ft above the headlights. For trucks, the figures are approximately 3.4 and 3.5 ft. A typical headlight beam pattern (General Electric 4002, lower-beam headlamp) varies from an intensity of 21,050 candelas at the center to less than 250 candelas within 6° to 8° vertically or 25° to 30° horizontally. The illuminance of a point on a distant surface is calculated from the intensity toward the point divided by the distance squared, or candelas per square foot (cd/ft^2).

Reflector Color

The reflector color affects the visibility not only because the eye is inherently less sensitive to some colors, but also because the light source is less than a perfect white. Yellow and yellow-green are the most highly visible colors. The light energy produced by an automobile headlight has more power proportionately in the red, yellow, and orange than white light, and less power in the blue and green. Because the eye is relatively insensitive to green and blue, these colors are especially low in visibility when used in reflectors illuminated by headlights.

ILLUSTRATIVE FIELD DATA AND SPECIFICATIONS OF REFLECTIVE MATERIALS

Specifications for reflective materials may be expressed in several ways: "reflectance" is common for marking devices, and $cd/fc/ft^2$ for reflective sheeting. This latter unit is discussed previously as SSL.

A reflective device may be evaluated by measuring the specific intensity (SI) of the device and comparing it to the SI of the source itself.*

$$SI = R/C \times D^2 (cd/fc) \tag{J-9}$$

in which D is the test distance, in ft; R is the value for the reflector, in fc, with the source and the meter at the same location; and C is the value for the source, in fc, when the meter is moved to the test distance. For a large, perfect mirror, SI = 6.25.† Light returned from a mirror is returned in the same direction, only at an entrance angle of 0°. A reflex reflector returns light over a large range of entrance angles, but is not as efficient as a mirror.

From Table J-2 it is apparent that approximately one-half the intensity is lost in going from a clear to a yellow reflector and one-half again is lost in going to red. These proportions can vary widely with the exact colors chosen.

To find specific luminance (SL) or specific intensity (SI) of a colored reflector, multiply the value for a clear reflector by a factor such as given in Table J-3.

The relative specific luminances for automotive reflectors are white 1.00; amber 0.25; and red 0.10 (SAE Standard J594d, 1967).

The illuminance produced by a corner-cube reflector is usually greater than that produced by a beaded reflector, often by a factor of 10 to 100 times, at least for small angles. This difference is generally not as important as it might appear, because of other variations in characteristics. Differences in illuminance are judged on a logarithmic scale; thus, a factor of 2 or 4 times a given illuminance value is of minor concern. As an observer approaches a reflector, the illuminance at his eye can change by a factor of 1,000 as the distance changes from 1,200 ft to 75 ft (*68*, p. 140). In all cases large (1 ft^2) samples would be visible well beyond 600 ft in clear weather. In general, about 3 to 5 times as much area of enclosed lens sheeting is required to be as visible as a corner-cube reflector or some encapsulated lens sheeting (see Table J-4).

Most reflector devices do not contain as much as one square foot of material. The Stimsonite 88 raised pavement marker has a reflective area of 3.4 $in.^2$ The angle at which this reflective area is projected in normal installation is approximately 60°, so that the effective or normal area is 1.7 $in.^2$ Cook (*68*), using a conservative threshold of 3×10^{-7} fc, calculates (p. 149) that 1.7 $in.^2$ of 3M red beaded material would be visible at about 180 ft with low beams and 370 ft with high beams. The red corner-cube reflector of the same size should be visible at 450 and 1,000 ft, respectively (see Table J-5).

Cook (*68*) has provided step-by-step procedures for calculating visibility of reflective devices. His procedure uses worksheets to organize the many details of the process. A typical result (adapted) is given in Table J-5. The values given are for new, clean material. The reflectors are less visible when dirty or worn. As a rough approximation, the corner cube, when reduced to about 10 percent of its new illuminance value, will have the same general visibility distance as new beaded material listed. It should be noted that for a given total area a more compact presentation is more visible; i.e., a disc is more visible than a thin strip.

The many possible combinations of entrance angle and

* From Test Method No. Calif. 669-A, April 6, 1970.

† With a mirror, the source-meter distance is doubled at 0° entrance angle. At 5 ft for a unit source: $SI = \frac{1.00/(2D)^2}{1.00/D^2} \times D^2 = \frac{0.01}{0.04} \times 25 = 6.25$ cd/fc.

TABLE J-2

MINIMUM SI[a] FOR NEW RAISED PAVEMENT MARKERS[b]

ENTRANCE ANGLE (DEG)	MINIMUM SI (CD/FC)		
	CLEAR	YELLOW	RED
0	3.0	1.5	0.75
20	1.2	0.60	0.30

[a] California Specifications (Sect. 85, CDH, Jan. 1971).
[b] At distance of 5 ft, 0.2° divergence angle.

TABLE J-3

ACTUAL VALUES[a] FOR THREE TYPES OF REFLECTOR[b]

DEVICE	ACTUAL VALUE	
	YELLOW	RED
Stimsonite 975	0.43	0.11
Reflecto-lite 110	0.58	0.17
3M Signal Delineator	0.55	0.18
Mean	*0.52*	*0.15*

[a] In terms of clear reflector as 1.00.
[b] Illuminated by a GE Par-46, 6v headlamp (*56*).

divergence angle in practical situations make prediction of the visibility distance inaccurate at best. Cook (*68,* p. 126) says:

> Assessment of a reflex reflector must be in terms of its function as a subunit of the total vehicular travel system, consisting of an incredibly large number of combinations of road configurations, ambient conditions, vehicle types, and driver capability. All combinations of divergence and entrance angles can occur.

The comparisons given in Table J-6 show the wide range in optical characteristics of different devices. (See also

TABLE J-4

CALIFORNIA SPECIFICATIONS FOR REFLECTIVE SHEETING (1970); MINIMUM VALUES AT 50-FT DISTANCE WITH A DIVERGENCE ANGLE OF ⅓°

COLOR	MINIMUM VALUE ($CD/FC/FT^2$) AT ENTRANCE ANGLE OF					
	0°	10°	20°	30°	40°	86°
High-intensity silver[a]	160.0	140.0	100.0	—	—	—
Silver or white	54.0	47.0	36.0	25.0	15.0	—
Yellow	20.0	17.0	13.0	—	—	—
Red	8.2	5.4	4.6	3.4	2.2	—
Green	4.2	3.0	2.2	1.5	1.0	—
Blue	3.4	2.2	1.7	—	—	—
White beaded foil striping tape	—	—	—	—	—	0.20
Yellow-beaded foil striping tape	—	—	—	—	—	0.17

[a] Encapsulated lens type; all other sheets are of the enclosed lens type.

Figs. J-2 and J-3.) For materials 1 and 2, changing the entrance angle has little effect; changing divergence angle makes a large difference for material 2, but only a small difference for material 1. For materials 3, 4, 5, and 6, changing the entrance angle has a large effect, whereas changing the divergence angle has only a moderate effect.

Even within one manufacturer, devices are designed for different purposes. Although large entrance angles seriously degrade performance, the extent can be controlled by design. For example, data provided in a letter (1971) from Stimsonite Division (Table J-7) show a new Type 2 rectangular delineator that is almost 1.5 percent as bright at 50° as it is at 0° entrance angle. Other devices drop to 0.3 percent, 0.1 percent, or less.

The relative importance of large changes in luminance must be pointed out: an example from a nomogram (*95*) with a given searchlight at sea gave visibility values of

TABLE J-5

CALCULATED PROBABLE DETECTION DISTANCES FOR RED REFLECTIVE MATERIAL[a] INSTALLED AT HEADLAMP HEIGHT

LAT. POS.[a] (FT)	ENT. ANGLE (DEG)	BEAM	DETECTION DISTANCE (FT) FOR AREA OF					
			BEADED REFLECTOR[b]			CORNER-CUBE REFLECTOR[c]		
			1.7 $IN.^2$	7.0 $IN.^2$	12 $IN.^2$	1.7 $IN.^2$	7.0 $IN.^2$	12 $IN.^2$
0	0	Low	180	270	310	450	730	840
		High	370	570	680	1040	1200+	1200+
	30	Low	120	220	250	350	450	600
		High	290	460	540	780	1070	1200+
22	0	Low	40	240	320	660	890	1010
		High	210	470	670	1030	1200+	1200+
	30	Low	—	150	220	420	670	760
		High	140	290	450	740	1010	1090

[a] Feet right of right headlamp. [b] Beaded sheet (3M 3272). [c] Stimsonite 12A.

TABLE J-6

RELATIVE EFFECTS OF A SMALL CHANGE IN DIVERGENCE ANGLE AND A LARGE CHANGE IN ENTRANCE ANGLE FOR DIFFERENT REFLECTIVE MATERIALS

MATERIAL			UNIT AREA	SAMPLE SPECIFIED LUMINANCE (CD/FC/FT²)[a]			
				ENTRANCE ANGLE = 0°		ENTRANCE ANGLE = 30°	
				DIVERGENCE ANGLE OF		DIVERGENCE ANGLE OF	
NO.	TYPE	COLOR	(IN.²)	0.10° (%)[b]	0.25° (%)[c]	0.10° (%)[b]	0.25° (%)[c]
1	3M Signal Delin.	Clear	16.2	262(100)	234(89)	216(82)	195(75)
2	Prismo	Clear	25.2	249(100)	48(19)	208(84)	41(16)
3	Stimsonite 975	Clear	7.1	3430(100)	1580(46)	456(13)	237(7)
4	Reflecto-lite 110	Clear	7.5	3420(100)	2055(60)	398(12)	266(8)
5	Stimsonite 12A	Red	6.5	480(100)	440(92)	40(8)	30(6)
6	3M Sheet—3272	Red	—	16(100)	12(75)	6.9(43)	5.1(32)

[a] SSL = (SI/area in ft²) × cos (entrance angle).
[b] Used as 100 percent.
[c] Relative to entrance angle of 0° and divergence angle of 0.10°.

TABLE J-7

EFFECT OF ENTRANCE ANGLE ON LUMINANCE OF FOUR CLEAR REFLECTIVE DEVICES[a]

ENTRANCE ANGLE	SAMPLE SPECIFIED LUMINANCE (CD/FC/FT²)			
	PAVEMENT MARKER	CIRCULAR DELINEATOR	NEW DELINEATOR	
(DEG)	NO. 88	NO. 975[b]	TYPE 1	TYPE 2
0	1270	3170	1730	950
10	890	2740	1250	750
20	560	1440	735	475
30	245	173	187	245
40	59	29	17	88
50	2.9	2.9	1.4	14

[a] Data from Stimsonite Division.
[b] Rotated for minimum value; can be almost 10 percent higher.

TABLE J-9

VISIBILITY OF VARIOUS TREATMENTS ON AN ISLAND TO THE LEFT OF THE ROADWAY[a]

MATERIAL			VISIBILITY DISTANCE
NO.	TYPE	COLOR	(FT)
1	8-In. barrier curb, beads on paint	Yellow[b]	225
2	5-In. corrugated curb, beads on paint	Yellow[b]	160
3	5-In. corrugated curb, beads on paint	Yellow[b]	170
4	8-In. barrier curb, reflective coating	Yellow[b]	150
5	⅝-In.-diam.[c] prismatic reflector in tunnel	Clear[b]	765
6	15-In.² reflective sheeting (flat top)	Amber	775
7	5×3-In. encapsulated reflector	Amber	810
8	10-w low-intensity curb light	Clear[b]	870

[a] Adapted from Refs. (*14, 34*).
[b] Not clearly stated in source reports.
[c] May have been 1½-in. diameter; reports unclear.

TABLE J-8

MEAN DETECTION DISTANCE IN FIELD TEST OF RED REFLECTORS WITH 6.5-IN.² AREA USING LOW BEAMS

DEVICE HEIGHT	FROM RIGHT HEADLIGHT		DETECTION DISTANCE (FT) FOR ENTRANCE ANGLE OF			
			BEADED SHEET		CORNER CUBE	
(FT)	(DIR.)	(FT)	0°	45°	0°	45°
2.5	Left	8	539	186	1166	260
	Right	2	565	250	1268	320
	Right	12	665	277	1034	480
4.0	Left	8	535	181	1105	239
	Right	2	584	225	1103	324
	Right	12	576	312	1253	367
Mean			*577*	*238*	*1155*	*332*
Mean of shortest distances			*468*	*128*	*821*	*132*

TABLE J-10

VISIBILITY DISTANCE OF FOUR MATERIALS UNDER LOW-BEAM HEADLIGHTS WITH OPPOSING HEADLIGHTS 20 FT AWAY IN ADJACENT LANE [a]

MATERIAL [b]		VIS. DIST. (FT) WHEN REFLECTOR IS			
		6.7 FT LEFT OF RIGHT HEADLIGHT		1.7 FT LEFT OF RIGHT HEADLIGHT	
NO.	TYPE	CLEAR WEATHER	RAIN [c]	CLEAR WEATHER	RAIN [c]
1	Beads in yellow paint	215	150	287	180
2	Yellow reflective coating	175	90	248	180
3	White reflective coating	204	90	265	190
4	⅝-In. prismatic reflector [d]	724	490	945	710

[a] From data in Ref. (*14*). [b] Painted on curb or mounted on curb top, center island. [c] Slow, steady drizzle; wipers on. [d] 0.306 in.^{2}

1.0 mi with SI = 5,000 cd/fc, 0.60 mi for 500 cd/fc, and 0.137 mi for 50 cd/fc. For a change of 100:1 in SI, the visual range changed only 3:1. Atmospheric transmissivity was 0.7, or a light haze.

Results reported (*68*) from tests of field visibility are as given in Table J-8.

Reflectors set at 45° angles toward the roadway were detected at average distances of 180 ft or more. The beaded reflector in this situation was detectable at almost the same range as the corner-cube reflector, although direct viewing (0° entrance angle) gave the corner cube a much greater advantage (see also Figs. J-2 and J-3).

Cook (*68*, p. 171) compares the calculated detection distances and the actual results found from his field tests on 15 subjects at 10 to 15 mph. The actual distances range from 1.3 to 3.2 times greater than those predicted by calculations. This made the actual distances for low beams close to calculated distances for high beams, which permits conservative estimates to allow for headlight misalignment. There are several possible reasons for this discrepancy, the most important of which is probably the threshold assumption.

A more practical criterion for visibility than the average detection distance is the distance at which relatively poor performance of normal subjects can be expected. This is often well below any "average" value, as indicated in Table J-8. If one uses the shortest detection distance of the 15 subjects in each condition, the means of these data (*68*) are closer to the calculated detection distances, and probably safer as a design criterion.

The effect of fog also can be calculated from existing information. Cook (*68*) lists ten descriptive conditions of fog. These are converted to attenuation factors for visibility distance. In moderate or dense fogs, 1 ft^2 of beaded material was never visible beyond 450 ft. In a few instances the corner cube was visible at this distance. For example, a moderate to thick fog reduces the illuminance of a reflector at 75 ft to approximately 0.64 times the clear-air illuminance. At 500 ft, this same fog would reduce the illuminance by a factor of 0.05. Thus, a reflector would have to be one-half again as bright at 75 ft to be seen in this fog as compared to one observed in clear weather. At 500 ft in fog, the reflector would have to provide 20 times as much illuminance to remain visible.

Further examples of field test visibility data are given in Tables J-9, J-10, and J-11. From these examples it

TABLE J-11

MEAN DETECTION DISTANCE OF YELLOW MATERIALS WITH LOW-BEAM HEADLIGHTS WITH AND WITHOUT OPPOSING HEADLIGHTS [a]

MATERIAL [b]	MOUNTING HEIGHT (IN.)	LOCATION (FT LEFT OF RIGHT HEADLIGHT)	DETECTION DISTANCE (FT)			
			CLEAR NIGHT		INCLEMENT [c] NIGHT	
			WITHOUT OPPOS.	WITH OPPOS.	WITHOUT OPPOS.	WITH OPPOS.
Glass (272 small mirrored beads: 1½ × 6¼-in. strip)	12	10	950	578	478	303
Beaded (3M, 3 × 4 in., sheet in acrylic)	12	10	845	530	463	276
Corner cube (Stimsonite 88)	8	10	561	408	324	246
Beaded paint, 5-ft curb strip	8	10	474	324	250	155

[a] Data from Ref. (*40*). [b] Manufacturers' identifications were not reported. [c] Not defined.

becomes obvious that no one visibility distance can be determined, but that a useful range can be found for practical applications.

In the study that provided the data for Table J-10, each of four subjects was to determine whether two or three units were installed in each trial approach. Distance is taken from location of the second unit, which was 15 to 20 ft beyond the first unit. During the three-month evaluation in Texas, the estimated reduction in reflectivity due to road film was 30 percent. When these units were later observed in a slow rain, the reduction was approximately 75 percent, although some cleaning effect resulted eventually. Units mounted low (e.g., 3 × 5-in. (high) beaded sheeting, mounted 2 in. above the island) are subject to severe road film problems and may require monthly cleaning in some seasons (*34*). James and Reid (*103*) reported that 83 to 90 percent of the Stimsonite 88 markers were serviceable after 15 to 22 months, although at 12 months the reflection of the red marker was reduced to 26 percent of original, and amber to 12 percent. Post-mounted delineators were reported to drop to less than 1 percent of new reflectance values in a few weeks. This does not, however, necessarily reduce effectiveness by the same proportion.

Another study (*40*) reported visibility of median delineators (Table J-11). The effect of opposing headlights 20 ft beyond the first delineator and across the 4-ft median is shown to be about a one-third reduction in distance. Inclement weather here reduces the distances almost to one-half those in clear weather.

CONCLUSION

This has been a brief introduction to the variables that are important in determining visibility distances and to the analytical techniques that can be applied. Because of the involved nature of the calculations for visibility distance estimates and their inherent inaccuracy, which results from imperfect assumptions and from variations in the observing population, it was believed that more detailed development was not appropriate. There are no simple formulas that can be applied for determining the visibility distance. Some of the general knowledge of vision and the more common units have been presented. Examples of the effects of changes in several variables and some data from field studies of visibility have been included in order to give a feeling for the relative importance of practical variations, both in the nature of the materials and in the situations in which they are employed.

APPENDIX K

EVALUATION OF COLORED PAVEMENT AS RELATED TO TRAFFIC PERFORMANCE *

The purpose of any delineation device is to provide information to the driver as to his travel path. This can be done by telling him either where to go (positive delineation) or where not to go (negative delineation). Colored pavement, defined here as color applied by any medium throughout the full lane, can serve both of these purposes. It can provide positive information by indicating the path the driver is to follow, as at an exit ramp or left-turn slot. At a lane drop situation, the use of colored pavement can warn the driver of impending narrowing of the pavement. Also, colored pavement at a stop approach can alert the motorist to an upcoming stop situation.

Colored pavement can be used to define the limits and the entire surface of the path the driver would ideally travel in making a transition from one roadway situation ment, defined here as color applied by any medium to another. It is apparent that transitional maneuvers are troublesome in that they (a) contribute greatly to impairment of traffic flow, and (b) account for the largest proportion of accident experience. It seems unlikely that driving skills, per se, can be blamed for such poor performance; hence, the weakness must exist in the driver's ability to search for, recognize, and process the information that guides him through a transitional state.

For many troublesome transitional situations—such as left-turn slots, exit and entrance ramps, stop approaches—colored pavement can provide necessary and continuous information to the driver so that he has ample time to locate and process the needed message.

However, colored pavement cannot be considered a panacea for delineation problems. Its cost alone argues against indiscriminate use. Furthermore, much of the value of color as an information transfer agent comes from the "arousal" or "startle" response that a sudden visual stimulus provides—in this case color contrast with the normal roadway. Widespread use of colored pavement probably would lead to adaptation on the part of the drivers, and its effectiveness, if any, would suffer.

The purpose of this study, then, was to evaluate the influence that colored pavement has on traffic behavior. Four common situations were chosen for study, as follows:

* By Hugh W. McGee, Research Assistant, The Pennsylvania State University.

1. Stop approach (red).
2. Lane drop (yellow).
3. Exit ramp (orange).
4. Left-turn slot (green).

PROCEDURE

Selection of Test Sites

If colored pavements are to be effective, their use should be restricted to unique and/or problem areas. Therefore, the selection of study sites was limited to locations with high accident records and nonuniform traffic flow. Personnel from the Pennsylvania Department of Transportation and the researchers jointly selected the study sites.

Altogether, 28 sites (12 stop approaches, 9 exit ramps, 5 lane drops, and 2 left-turn slots) were selected for colored pavement treatment and study. All of the sites were located in the four-county area surrounding Harrisburg, Pa.

Installations

The colored pavement material was placed by highway maintenance crews from the Pennsylvania Department of Transportation. The material, known commercially as Pavebrite 90, is similar to asphaltic concrete except that a synthetic resin is used as a binder. It was placed in ½- to ¾-in. layers over the existing pavement.

The colors used for this experiment were red for stop approaches, green for left-turn slots, yellow for lane drops, and orange for deceleration ramps. The colors were selected on the basis of a proposed recommendation from Institute of Traffic Engineers Committee 5H(*65*).

At the stop approaches the length of red-colored material varied from 300 ft to 750 ft, depending on the geometry and the sight distance. Paving for the orange exit ramps began at the entrance to the deceleration lane and continued onto the exit ramp. Again, the geometry determined the length of the section. Gore markings and exit ramp edge lines were replaced at all the ramps. Yellow-colored material was placed at lane drops that were previously marked by double yellow lines and yellow zebra striping. The green material for left-turn slots was placed throughout the entire turn lane, previously defined by paint markings. White boundary lines were replaced.

In an effort to improve nighttime color visibility, reflectorized glass beads were installed at a few sites. Chromospheres with a bead size of 12-20 mesh were spread at an application rate of 0.1 lb/ft^2. The beads were machine spread before final compaction.

Following installation of the colored pavement, the Pennsylvania Department of Transportation issued a news release explaining the meaning of the colors. This information was transmitted through various media to the local motorists. No attempt was made in this study to evaluate the effectiveness of the news coverage.

Field Data Collection

A before-and-after study of traffic behavior variables was used as a measure of effectiveness. The study period was too short to use accident record comparisons as an effectiveness criterion.

Stop Approaches

By the use of radar, vehicular spot speeds were taken at 200 ft and 500 ft from the intersection. At each location speeds of 100 free-flowing cars were recorded. A car was considered free-flowing when there were no other vehicles preceding or at the intersection. Also, the locations (in 50-ft segments up to 350 ft from the intersection) of the first brake light application of 100 cars were observed. Two sites, one of which had reflectorized beads, were studied at night.

Lane Drop

The number and pattern of encroachments on the lane drop areas were recorded in a before-and-after study. A vehicle was considered encroaching when at any time it crossed into the lane drop area. The number of encroachments as a ratio to the total volume passing through the lane drop area was used as one effectiveness parameter. The second measure was lateral placement of vehicles as they passed through the section. Visual observation was made of tires crossing 1-ft tape segments. Third, the longitudinal position of vehicles changing lanes prior to the lane drop area was recorded in 50-ft segments. Night data were taken at four sites.

Exit Ramps

Two spot speeds, brake light applications, and erratic maneuvers were recorded. Speeds of 100 free-flowing vehicles were taken at the gore area and farther along the exit ramp. The location, by 50-ft segments, of each vehicle's first brake light application upon entering the deceleration lane was noted. Also, any erratic maneuvers, such as crossing over the gore markings or sudden stopping or swerving, were recorded. Two exit ramps (one with beads) were studied at night.

Left-Turn Slots

Although before data consisting of spot speed and point of entry into the left-turn slot were collected, it was decided not to gather after data for this situation. Due to low volumes at the site, insufficient sample sizes precluded any meaningful statistical analysis. In addition, construction near the intersection further reduced volumes during the after period. However, documentary movies were taken at these sites.

RESULTS

Stop Approaches

Spot Speeds

The speed data were statistically analyzed by using a Student's *t*-test for testing significant differences between means of two populations. Mean speeds at 500 ft and 200 ft in the before study were compared with the after speeds at the same locations. Also, an *F*-test was used to determine whether the variances of the speeds were significantly different.

Table K-1 gives the mean speeds, their variances, and the results of the statistical tests previously mentioned. The results of the *F*-tests indicate that in only one case was there significant reduction in variance of speeds for the after study. This situation occurred at the 500-ft mark at S4-A during the night. All other cases resulted in no significant difference. One could theorize that if red-colored pavement is effective, it should reduce the variance of the speeds (i.e., group the speeds closer around the mean), at least at the 200-ft mark. The results indicate that this did not happen.

Several significant differences in the mean speeds were found, however. It would seem that the ideal change caused by the red treatment would be a reduction in the mean speed at 200 ft. This, in fact, did occur at five of the nine sites studied during the day. At the other four sites, the change was not significant. (Although S5-A and S5-B are given in the table, they are not analyzed. Between the before and the after study periods a red flashing light was installed; therefore, any differences noted cannot be attributed directly to the presence of the colored pavement.) One additional site (S1), which has reflectorized beads, showed a significant reduction at night. It is also interesting to note that at two sites (S3-B and S10) there was a significant increase at 500 ft, and at 200 ft the S3-B mean speed in the after study was lower, but not significantly. Only three sites (one of which was at night) showed no change in either the 500- or 200-ft locations.

Brake Light Applications

The second effectiveness criterion for red-colored pavement was the observation of brake light applications. Table K-2 gives the mean distance from the stop line and variance of the brake light applications and the results of

TABLE K-1

SUMMARY OF SPEED DATA FOR STOP APPROACHES

SITE AND CONDITION	DIST. FROM STOP LINE (FT)	MEAN SPEED (MPH)		SIGN. DIFF.[a, b]	VARIANCE		SIGN. DIFF.[b, c]
		BEFORE	AFTER		BEFORE	AFTER	
S1 Day	500	44.7	42.1	Yes (R)	46.82	45.36	No
	200	34.7	34.9	No	29.07	27.62	No
S1 Night	500	39.0	39.6	No	63.28	54.02	No
	200	32.9	24.2	Yes (R)	47.33	47.23	No
S2-A Day	500	36.9	37.7	No	27.94	26.75	No
	200	31.4	28.1	Yes (R)	16.38	18.36	No
S2-B Day	500	22.2	23.0	No	8.57	11.96	No
	200	23.1	23.1	No	7.99	10.66	No
S3-A Day	500	36.7	32.4	Yes (R)	29.39	31.20	No
	200	32.1	27.0	Yes (R)	19.90	19.11	No
S3-B Day	500	34.3	37.4	Yes (I)	28.91	30.00	No
	200	30.2	29.6	No	18.30	23.93	No
S4-A Day	500	33.4	31.7	No	37.17	54.48	No
	200	29.9	38.4	Yes (R)	14.77	22.13	No
S4-A Night	500	32.3	31.1	No	41.06	21.33	Yes (R)
	200	27.2	27.8	No	17.40	15.45	No
S4-B Day	500	38.8	34.5	Yes (R)	20.54	30.52	No
	200	30.3	27.9	Yes (R)	23.30	20.23	No
S5-A Day	500	34.2	40.7	Yes (I)	38.55	34.96	No
	200	32.5	29.1	Yes (R)	30.05	20.71	No
S5-B Day	500	31.9	32.7	No	19.76	23.92	No
	200	35.7	29.2	Yes (R)	28.73	26.74	No
S8 Day	500	36.6	35.7	No	28.49	26.08	No
	200	31.7	32.3	No	20.50	22.16	No
S10 Day	500	36.2	40.1	Yes (I)	30.58	25.32	No
	200	33.0	29.7	Yes (R)	19.83	20.61	No

[a] Significant difference based on *t*-test at 95 percent level of confidence.
[b] R = reduction in after study; I = increase in after study.
[c] Significant difference based on *F*-test at 95 percent level of confidence.

TABLE K-2

SUMMARY OF BRAKE LIGHT APPLICATIONS FOR STOP APPROACH

SITE AND CONDITION	MEAN DIST. FROM STOP LINE (FT) BEFORE	AFTER	STAT. SIGN.[a, b]	VARIANCE BEFORE	AFTER	STAT. SIGN.[c, b]
S1 Day	215.7	247.2	Yes (I)	6256.8	5547.3	No
S1 Night	231.9	229.0	No	4579.2	3883.8	No
S2-A	261.8	257.6	No	2617.2	5446.4	No
S2-B	262.6	290.2	Yes (I)	11214.8	5323.2	Yes (R)
S3-A	179.5	159.8	No	6366.4	4366.6	Yes (R)
S3-B	242.2	262.5	Yes (I)	4577.9	4226.3	No
S4-A Day	310.0	306.3	No	1675.0	1894.0	No
S4-A Night	309.5	312.5	No	1634.75	868.8	Yes (R)
S4-B	308.5	318.5	No	2590.2	1182.8	Yes (R)
S5-A	288.8	275.2	No	2917.2	5606.2	Yes (I)
S5-B	286.9	294.0	No	3552.3	2739.0	No
S8	233.0	213.3	No	4811.0	7943.2	Yes (I)
S10	287.8	296.8	No	3293.7	2383.2	No

[a] Statistical significance based on normal distribution test at 95 percent level of confidence.
[b] R = reduction in after study; I = increase in after study.
[c] Statistical significance based on *F*-test at 95 percent level of confidence.

the statistical testing. The *F*-test results show for sites studied during the day that at six locations there was no change in the variance, three sites displayed a significantly reduced variance, and at one site there was a significantly increased variance. For the two sites studied at night, one showed a significant reduction, whereas the other had no change. Again, it would be expected that a beneficial aspect of red-colored pavement would be a reduction in the variance. Considering both day and night studies, this occurred at only four of the eleven sites. It does not appear that this objective was decisively met.

Comparison of the before and after mean distance for brake light application revealed that three locations (all daytime) had a significant increase. All other sites had no significant change. It can be argued that an increase in the mean distance for brake light application is a worthwhile effect. Because these locations were areas with run-STOP-sign accidents, some drivers were not getting cues of a STOP sign ahead in sufficient time. The earlier application of brakes with the presence of colored pavement would indicate, then, that drivers were aroused by the treatment. This apparently happened at the three locations.

Lane Drops

Encroachments

Table K-3 is a summary of the data analysis for encroachments on the lane drop areas. A chi-square test was used to determine if there was a significant change in encroachments between the before and after conditions. Again, a 95 percent level of confidence was selected. The analysis indicates that at four sites (LD1, LD2, LD4A, and LD4B) the number of encroachments during the day was significantly reduced with the application of yellow-colored pavement. Also, at two sites (LD4A and LD4B) studied at night there was a significant reduction in encroachments. At the other two sites (LD5 and LD6) there was no significant change in either the day or the night study.

It was hypothesized that yellow-colored pavement used

TABLE K-3

SUMMARY OF LANE DROP ENCROACHMENTS

SITE AND CONDITION	ENCROACHMENTS PER TOTAL VOLUME OBSERVED ON: PAINTED AREA	COLORED PAVEMENT	CHANGE (%)	SIGNIFICANCE[a]
LD1	50/77	20/140	−49.3	Yes
LD2	50/260	22/260	−10.7	Yes
LD4-A Day	50/542	18/542	−5.9	Yes
LD4-A Night	50/251	8/247	−16.9	Yes
LD4-B Day	50/447	24/474	−6.1	Yes
LD4-B Night	50/340	16/340	−10.0	Yes
LD5 Day	50/97	50/103	−3.5	No
LD5 Night	50/160	50/118	+11.2	No
LD6 Day	50/317	50/239	+4.9	No
LD6 Night	50/160	50/127	+8.1	No

[a] Statistical significance based on chi-square test with Yates adjustment with 95 percent level of confidence.

for a lane drop situation should reduce the number of encroachments on the restricted area. It appears that the colored treatment has met this objective. Although two sites showed no significant change in the after study, it should be noted that they are not true lane drops. At LD5 the treatment was applied to the right-most lane of a divided highway to "push" traffic over to the left lane, thereby avoiding conflicts with traffic merging from the right (I-83). However, at this location there is good visibility and, apparently, drivers see no reason to move over, particularly when there are no vehicles merging from the right. In addition, local drivers are accustomed to remaining in the right lane in order to exit at the next ramp farther upstream. LD6 is located on I-83 on a crest vertical curve preceding a lane-drop exit ramp and serves to push through drivers to the through lanes on the left. The visibility is good at this site, also, and local drivers tend to drive through the "lane drop" area on their approach to the exit ramp.

Lateral Placement

In an effort to determine if yellow-colored pavement affects the vehicle's lateral position on the lane, placement of the right front tire was noted. Table K-4 gives a summary of the data and the results of the statistical analyses. The mean distances given for sites LD1 and LD5 are measured from the edge of colored pavement into the traveled lane; all others are taken from the edge of pavement.

The results of the *F*-test indicate that at five study situations there was no significant change. At one site (LD5, day and night) there was a significant reduction, and at one site (LD1) there was a significant increase in the variance for the after study. These results would indicate that colored pavement does not affect the variance of lateral placement in any definitive manner.

The *t*-test comparing the differences between means also shows mixed results. At three sites (LD1, LD2, and LD5 day and night) there was a significant move away from the treatment area; at two sites (LD4A night and LD4B) vehicles moved closer to the colored pavement; and the remaining study situations showed no change in placement for the before and after conditions. As in the analysis of the variances, the results of the *t*-test show no marked trend.

Lane Changes

The third study criterion for evaluating the use of colored pavement at lane drops was the locations where vehicles initiated their lane change into the through lane. This was recorded by 50-ft segments on the approach roadway.

Table K-5 gives the mean distance of lane change for the before and after conditions, and the results of the *t*-test to compare the respective means. At three of the sites (LD2, LD4A night, and LD4B night) the samples are too small to draw meaningful conclusions. Of the remaining sites, only one (LD6) showed any significant change. At this site vehicles began their lane change farther upstream from the lane drop area in the after study. In general, however, the results of this phase are inconclusive.

Deceleration Ramps

As mentioned previously, data collected at exit ramps consisted of two spot speeds, point of first brake light application prior to gore area, and any erratic maneuvers.

Speeds

Table K-6 gives the mean speeds and the variances for the before and after conditions, as well as the results of the appropriate statistical analyses. Locations A and B refer

TABLE K-4

SUMMARY OF LANE DROP LATERAL PLACEMENT

SITE AND CONDITION	MEAN DIST. OF RIGHT FRONT TIRE (FT) [a] BEFORE	AFTER	SIGNIFICANCE [b, c]	VARIANCE OF DISTANCE BEFORE	AFTER	SIGNIFICANCE [d, c]
LD1	1.23	1.80	Yes (+)	2.23	1.52	Yes (+)
LD2	4.55	4.11	Yes (+)	2.02	1.53	No (+)
LD4-A Day	2.06	2.20	No (−)	1.69	1.28	No (+)
LD4-A Night	2.71	3.04	Yes (−)	1.54	1.62	No (+)
LD4-B Day	2.09	2.60	Yes (−)	1.20	1.48	No (−)
LD4-B Night	1.87	1.73	No (+)	0.95	0.89	No (+)
LD5 Day	0.87	1.78	Yes (+)	1.47	3.21	Yes (−)
LD5 Night	1.37	1.83	Yes (+)	1.72	3.39	Yes (−)

[a] From edge of pavement; except LD1 and LD5, which are from edge of colored pavement into the traveled lane.
[b] Statistical significance based on *t*-test at 95 percent confidence.
[c] + = vehicles moved away from treated area in after study. − = vehicles moved closer toward treated area in after study.
[d] Statistical significance based on *F*-test at 95 percent confidence.

TABLE K-5

SUMMARY OF LANE CHANGES AT LANE DROP

SITE AND CONDITION	NO. OF OBS.		MEAN DIST. FOR LANE CHANGE (FT)		CHANGE [a] (AFTER-BEFORE)	SIGNIFICANCE [b]
	BEFORE	AFTER	BEFORE	AFTER		
LD1	19	51	117.11	156.37	+	No
LD2	7	23	232.14	135.87	—	Yes
LD4-A Day	26	50	115.38	145.00	+	No
LD4-A Night	18	15	141.67	175.00	+	No
LD4-B Day	45	28	135.00	173.21	+	No
LD4-B Night	12	8	120.83	193.75	—	No
LD5 Day	22	63	138.64	123.41	—	No
LD5 Night	52	101	128.85	133.42	+	No
LD6	71	23	100.35	177.17	+	Yes

[a] + = move away from lane drop in after study; — = move toward the lane drop in after study.
[b] Statistical significance based on t-test at 95 percent confidence.

to the exit gore area and farther down the exit ramp, respectively, and are the points where the speeds were taken.

The results of F-tests for variances show that a significant change occurred after the application of colored pavement at only four of the data collection points. There was a significant reduction in the variance at R6, location A, at night. However, during the day at the same ramp, as well as at R4, location A, there was a significant increase. With so few sites showing any change, no conclusions can be drawn regarding the variances of spot speeds.

Several of the sites showed significant changes in the mean speeds. However, the results are somewhat surprising in that at six study situations there were significant increases in speeds at both location A and location B. At two sites (R4 and R5) there was a significant decrease in mean speeds. No significant change was noted at R9 at night.

TABLE K-6

SUMMARY OF EXIT RAMP SPEEDS

SITE AND CONDITION	LOCATION	MEAN SPEED (MPH)		SIGN. DIFF.[a, b]	VARIANCE		SIGN. DIFF.[c, b]
		BEFORE	AFTER		BEFORE	AFTER	
R1	A	33.72	39.80	Yes (I)	38.51	36.36	No
	B	33.70	37.72	Yes (I)	20.31	24.12	No
R2	A	42.86	45.90	Yes (I)	57.07	51.23	No
	B	39.24	45.38	Yes (I)	42.85	40.06	No
R4	A	29.61	27.02	Yes (R)	8.19	18.63	Yes (I)
	B	25.65	23.12	Yes (R)	7.99	8.39	No
R5	A	30.96	28.18	Yes (R)	11.96	14.88	No
	B	29.91	28.04	Yes (R)	10.60	10.38	No
R6 Day	A	31.99	32.92	No	7.25	19.79	Yes (I)
	B	20.10	25.56	Yes (I)	1.40	10.46	Yes (I)
R6 Night	A	26.56	30.28	Yes (I)	19.89	11.42	Yes (R)
	B	24.82	26.90	Yes (I)	10.65	11.59	No
R8	A	27.74	29.42	Yes (I)	16.70	16.83	No
	B	24.80	26.14	Yes (I)	11.92	13.52	No
R9 Day	A	27.54	29.94	Yes (I)	15.66	18.70	No
	B	29.16	31.00	Yes (I)	13.02	16.65	No
R9 Night	A	26.80	26.96	No	13.70	16.32	No
	B	28.82	27.90	No	24.98	17.08	No

[a] Statistical significance based on t-test at 95 percent confidence.
[b] R = reduction in after study; I = increase in after study.
[c] Statistical significance based on F-test at 95 percent confidence.

TABLE K-7

SUMMARY OF BRAKE LIGHT APPLICATIONS FOR EXIT RAMPS

SITE AND CONDITION	BRAKE LIGHT APPLICATION POINT, MEAN DISTANCE FROM GORE AREA (FT)			SIGN. DIFF.[b]
	BEFORE	AFTER	CHANGE[a]	
R1	116.0	135.0	+	No
R4	179.4	126.2	—	Yes
R5	114.1	103.5	—	No
R6 Day	105.4	133.8	+	Yes
R6 Night	92.9	80.9	—	No
R8	65.4	49.3	—	No
R9 Day	124.0	121.0	—	No
R9 Night	107.3	101.0	—	No

[a] + = brake application was farther from gore area; — = brake application was closer to gore area.
[b] Statistical significance based on *t*-test at 95 percent confidence.

One reason the speeds decreased at R4 and R5, while increasing at the other ramps, may be that these two ramps have very short deceleration lanes and high exit ramp curvatures. It is possible that the colored pavement has emphasized this condition, and therefore vehicles are going slower.

Brake Light Applications

Table K-7 gives the mean distance from the gore area of the brake light application and the statistical results of this phase of the study. A *t*-test was employed to test the difference between the means. The results indicate that at only two sites (R4 and R6) were there significant changes, and these were mixed. The mean distance from R4 moved closer to the gore area whereas at R6 it moved farther away. There does not appear to be any trend in the way colored pavement affects brake light application at the exit ramps studied.

Erratic Maneuvers

Any erratic maneuvers that occurred at the exit ramps were noted. However, because these occurred infrequently at all the sites, no meaningful statistical analysis could be applied to the data; only general observations can be made.

It was noted during the data collection and other inspection visits to the exit ramps that some motorists, especially those from out of state, were confused by the colored treatment. This was manifested by sudden braking and late entry into the exit ramp. Also, many drivers appeared reluctant to drive on the colored pavement, at least initially. At one site (R2), however, an immediate improvement was observed. At this site there is a second ramp that turns right off the main exit ramp. Previously, vehicles frequently crossed over the gore marking at this second exit area. With the colored pavement defining the main ramp, vehicles no longer do this.

CONCLUSIONS

This appendix deals with just one phase of the evaluation of colored pavement material—its influence on traffic behavior. Conclusions regarding its effectiveness and recommendations for its use as a delineation treatment must be viewed in light of other test results.

The conclusions of this phase of the colored pavement study can be summarized as follows:

1. The presence of red-colored pavement at a stop approach has the tendency to reduce mean speeds on the approach. The study results indicate that speeds 200 ft before the intersection were almost always lower after the installation of colored pavement. The red pavement did not have any influence on the position of vehicle brake light applications.
2. The use of yellow-colored pavement to indicate a lane drop area can reduce the number of encroachments on the restricted area. However, where it was used as a channelization device on a four-lane, divided highway it did not reduce the number of encroachments. Also, colored pavement did not measurably affect the lateral placement of vehicles passing through the treated section.
3. Orange-colored pavement on exit ramps does have an influence on vehicle speeds. In most instances the mean speeds were higher for vehicles exiting after installation of the colored pavement. This may indicate a higher degree of driver confidence. The orange pavement did not affect the location of brake light applications.
4. No conclusions can be stated regarding the influence on traffic behavior of green-colored pavement for left-turn lanes.
5. For all three situations, colored pavement did not influence traffic behavior at night in any consistent manner. This was to be expected, because the colors, even when reflectorizing beads are applied, cannot be distinguished readily at night.

The foregoing conclusions are constrained by the following qualifications:

1. Although local drivers were made aware of the meaning of the colored pavement, non-familiar drivers probably did not recognize the color codes (at least not immediately). The effect on the results cannot be ascertained.
2. More than a month was allowed for drivers to become acclimated to the color treatment. However, driver reaction to the colored pavement after an extended period of time is not known. In addition, it has been observed that the color at many locations has further bleached out and is less startling.

APPENDIX L

PHYSICAL CHARACTERISTICS OF COLORED PAVEMENTS *

The original problem statement (Objective 7) called for an evaluation of colored pavements, including evaluation of the physical characteristics and a comparison of their performance with that of conventional asphaltic and portland cement pavements.

Pavements with a mixture of synthetic resinous binder, special colored pigments, and carefully selected aggregate were evaluated within this project. Although other types of colored pavements (thin-film types, addition of color to portland cement concrete, and special colored aggregate) are mentioned in the literature, they were not considered as promising or as widely applicable as the resin binder type.

This same material, without the colored pigments, has been used extensively in Pennsylvania to repave bridge decks. This experience indicates the wear characteristics of this material to be at least equal to those of most asphaltic concrete overlays, and no further attention was directed to durability.

The two major characteristics investigated within this study were skid resistance and the color visibility. Skid resistance will be of great importance if the use of colored pavements becomes widespread, because they will generally be used in critical situations where maneuvering capability will be at a premium. The visibility characteristic is of interest, of course, because these pavements conceptually rely on color visibility for their effectiveness—if the colors are not discernible, the effectiveness will be lost. It is important, then, to know under which combinations of lighting, rainfall, aging, wear, etc., which of the colors, if any, will be seen.

SKID RESISTANCE

In many applications, colored pavements are placed along the full width of a lane and at critical sections of the road, such as prior to a stop intersection. Thus, consideration should be given to the potential slipperiness of colored pavements.

The objective of this task was to evaluate the skid resistance of colored pavement as compared to those of portland cement concrete or asphaltic concrete pavements. To do so, field skid resistance tests using the Penn State Road Friction Tester (Fig. L-1) were made on a sample of colored pavement installations at three different time periods.

The test consisted of making at least three passes by the road friction tester on both the colored pavement section and the standard pavement immediately before or after the colored section. The tests were conducted one, three, and five months after installation.

Table L-1 gives the skid resistance values at 40 mph, for the colored pavement and standard pavement sections tested. Tests conducted three months after installation did not include sections of the standard pavement.

Initially, the colored pavement demonstrated very high skid resistance; but an appreciable reduction was noted during subsequent tests. However, in every comparison, except for the left-turn slot site, the skid resistance of the colored pavement was higher than that of the standard pavement (the values were nominally the same at the left-turn slot location). Also, at those sites where glass beads were applied for reflectorization, the skid resistance values were adequate. The bead application was intended to be 0.1 lb/ft^2, but the actual density was somewhat less due to dislodging of the beads under traffic.

COLOR VISIBILITY

The objective of this phase of the research was to determine pairs of different colored pavements producing a sufficiently high degree of contrast to permit their use to facilitate drivers' perception and thus contribute to the ability to convey information. In considering delineation as the use of perceived differences in color or brightness to transfer information, and the definition of contrast as the intensification of the perceived difference between neighboring colors, this research was conducted to determine the maximum potential for contrasting colored pavement as a delineation treatment.

The program for this part of the project included the conduct of laboratory tests of the visual characteristics of colored pavement materials under various lighting and environmental conditions, the objective being to determine a comparative measure of the color contrast obtainable for different colored pavement samples with portland cement concrete and standard asphaltic pavement samples. This information could then be used in the evaluation of the effectiveness of this treatment for specific locations and to define the lighting necessary to achieve a specified contrast level.

A necessary step in this testing was the definition of a measure of the parameter being evaluated. Once this measure was established, direct comparisons under different environmental and lighting conditions could be made. However, because color, and thus color contrast, is a concept rather than a physical parameter, further tests were conducted to establish the correlation between the selected measure and the drivers' ability to discern differences.

Inasmuch as the chosen method for testing the color of various samples utilized reflectance measures, it is essential to realize that these reflectance measurements depend on several factors, as follows:

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Figure L-1. Penn State road friction tester.

1. The reflectance of any surface is a function of the angle of incidence of the light source.
2. In addition to the reflectance at a given angle of incidence, there is also reflectance from light incident from all sides; i.e., reflectance is also a function of stray light that may be present.
3. Reflectance depends on the spectral composition of the incident light.
4. Reflectance is a function of the spectral absorption characteristics of the material.
5. Reflectance measures also depend on the spectral sensitivity of the detector.

From the definition of reflectance as the ratio of reflected flux to incident flux, and intensity as the flux per solid angle, comparative spectral properties are independent of the absolute intensity if the results of the reflectance readings are normalized. So long as the angle of incident light, angle of viewing detector, distance of the light source from the sample, distance of the detector from the sample, type and spectral composition of incident light, response characteristics of the detector, and environmental conditions are held constant, the spectral properties of the sample reflectance are independent of the flux per unit solid angle of incidence.

In the experimental work conducted in this phase of the project, comparative data rather than absolute values of the spectral characteristics of the pavement samples were used. The rationale for this approach was the desire to develop an understanding of potential color contrast obtainable with this treatment. The dependent variable is called the chromaticity vector, and it is a measure of the differences in two spectral curves, or the color contrast. Because interest was centered on the differences or contrast between two observations, the measure was calculated from

TABLE L-1

SKID RESISTANCE OF COLORED PAVEMENTS

SITE			AVE. SKID NO.[a]		
NO.	TYPE	SECTION	1 MO	3 MO	5 MO
S1	Stop approach	Colored pavement[b]	66.0	63.3	57.0
		Asphaltic concrete	51.0	—	46.3
S2-B	Stop approach	Colored pavement	64.0	59.0	56.7
		Asphaltic concrete	52.0	—	43.7
R2	Exit ramp	Colored pavement	65.5	64.0	45.0
		Portland cement concrete	42.0	—	30.0
R9	Exit ramp	Colored pavement[b]	59.0	42.3	45.0
		Portland cement concrete	41.0	—	29.3
LD 4	Lane drop	Colored pavement	70.5	67.6	46.7
		Portland cement concrete	60.5	—	42.7
LT 2	Left-turn slot	Colored pavement[b]	—	50.3	59.6
		Asphaltic concrete	—	—	63.0

[a] Average of three or more passes.
[b] With glass beads.

comparative normalized rather than absolute values of the spectral curves.

The following independent variables were considered in this experiment:

1. Type of light sources.—Fixed lighting (such as Lucalox, mercury vapor, fluorescent, incandescent) and movable lighting (like the auto headlamp).
2. Type of reflecting surface.—Non-reflectorized colored pavement, reflectorized colored pavements, standard asphaltic pavement, portland cement concrete pavement.
3. Surface condition.—Wet and dry.
4. Various sizes of beads used on the colored pavement samples.
5. Angle of incidence of fixed lighting.

The chromaticity vector is a measure of the differences in the spectral distribution of the reflected light measured in three separate increments of wavelength. The study was designed to determine the relationship between this measure and the independent variables.

Instrumentation

To obtain the spectral curves necessary to determine the chromaticity vectors, a laboratory was set up to obtain readings simulating drivers' vision angles.

The experimental equipment was chosen after making a comprehensive literature review in this field of laboratory testing, discussions with the illuminating engineers at General Electric's Research Laboratory at Nela Park, Cleveland, and consideration of the specific objective of this experiment as mentioned earlier.

American Instrument Company's blank subtract microphotometer was chosen for measurement of reflectance, and a photomultiplier tube was chosen as the sensing equipment. The equipment assembly was designed and fabricated to suit the purpose of the experiment.

The equipment assembly was mounted on a baseplate that had four set screws to obtain the desired angle of the sensing tube to simulate the driver's eye. The sample stand was designed to allow vertical height adjustment. A structure was erected in the laboratory to screen the incident lights to prevent their being sensed by the detecting equipment.

The detecting equipment assembly consisted of three parts, as follows:

1. The tube and baseplate assembly.—The tube permitted focusing on a specific location on the pavement sample. The baseplate supported the tube in a fixed position at the prescribed angle of detection.
2. Monochromator.—This is a device by which different wavelengths of the light energy reflected from any surface or medium can be separated discretely. This is achieved by using a diffusion grating and detecting the reflected light from this with the help of a detector. The grating deflects only one wavelength at a time, permitting the separation of a light source into its component spectral characteristics.
3. Photomultiplier.—A photomultiplier tube with an adjustable housing that has variable aperture was used to detect the ray (with singular wavelength) deflected from the monochromator.

The energy detected by the photomultiplier tube was transformed to electrical energy and indicated in the AMINCO blank subtract microphotometer.

Four colored pavement samples (red, orange, yellow, green) were made in the materials laboratory at Wayne State University.

The specification for the samples was provided by the Pennsylvania Department of Transportation to assure that the laboratory samples duplicated field application as nearly as possible. The materials used were fine aggregate (all passing through No. 8 sieve), synthetic resin (binder), and various colored pigments and both clear and color-coated beads.

For the beaded samples, the application rate was 10 lb/100 sq ft, applied by hand spreading. The beads were then rolled into the surface with a 2-ft-diameter, hollow, steel roller filled with water. Although this did not give the degree of compaction one would expect in the field, the simpler method of compaction was used because the only interest was in the color reflectivity of the surface of the pavement samples and the samples were not subjected to stability tests.

All general conditions in the specifications for "Pigmented Synthetic Resin Wearing Course FJ-1" of the Pennsylvania Department of Transportation were followed.

Experimental Procedure

The pavement sample was placed on the sample stand, leveled with the help of the set screws; the height of the sample was set for the particular test; and the entire assembly was covered with a black cloth to eliminate stray light on the detection equipment.

The position of the light was fixed according to the required angle of incidence. The height of the table over which the detecting equipment assembly was placed was set, and the set screws of the baseplace were adjusted to give the proper angle of detection and to focus the pavement sample on the sample stand through an opening in the curtain. The focusing was done through the monochromator box, which has a narrow slit opening. With the monochromator door and the photomultiplier shutter closed, the incident light was turned on. The shutter of the photomultiplier tube was then opened and the microphotometer readings were observed for the length of visible spectrum to determine the most appropriate aperture for the photomultiplier tube and meter multiplier of the microphotometer. Each time a variable was changed, this process had to be repeated.

Data were taken by selecting the wavelength to be measured; then the microphotometer reading for that wavelength, which represents the percent transmission, was noted. These readings were continued at preselected intervals of wavelength until a complete set of readings for a sample was obtained. The data were collected for all the experiments as described under "Design of Experiment," and recorded in the format of Table L-2. The wavelengths chosen covered the visible spectrum and were nearly equally spaced, as indicated in Table L-2.

The readings were plotted to obtain the spectral distribution curves (Fig. L-2). All the curves plotted from the

TABLE L-2

EXAMPLE OF DATA RECORD FOR LUCALOX LIGHT SOURCE, 90° ANGLE OF INCIDENCE, RED PAVEMENT, AND 4° VIEWING ANGLE

Wave length (nannometers)	405	437	460	500	545	580	630	680
Transmission (%)	11	12	15	17	12	21	46	24

tests were then normalized so that the total area within the visible spectrum was constant. The basic objective of normalizing was to avoid any effect of dissimilar intensity of different light sources incident on the pavement samples and to facilitate comparison of the color contrasts of various combinations of pavement samples. These data were then replotted, and the areas under various color bands within the visible portion of the normalized spectral curves were calculated. The readings taken in the laboratory were for discrete wavelengths, and the areas were computed using a straight-line interpolation between the data points. The results of the data collection are given in Table L-3.

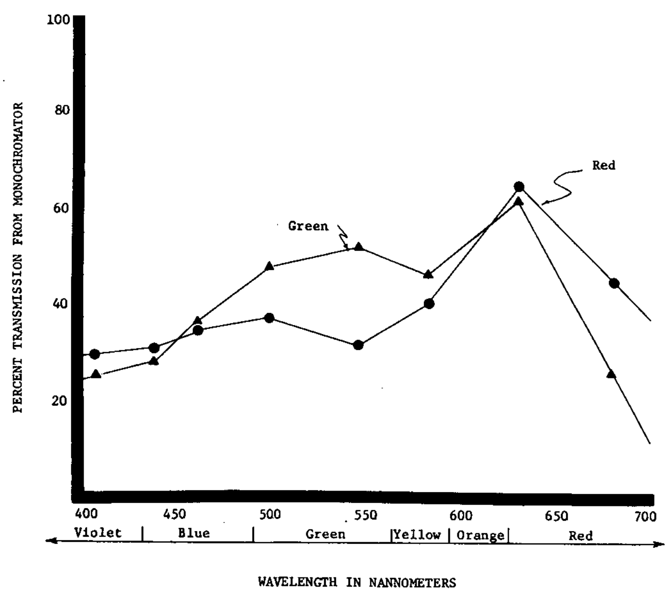


Figure L-2. Spectral distribution curves for red and green pavement sample under Lucalox lighting.

The areas under the blue, green, and red color bands were used to construct the chromaticity vectors. Vectors could be constructed from any two planes with a common axis, but the literature search did not indicate that other colors are used to define these diagrams, so this set was used. The areas under red, blue, and green color bands were converted into percentages for the determination of the chromaticity vector. These percentages were plotted on two orthogonal planes—red and blue, and red and green. The vector length between any two samples could then be determined by direct measurement of the spatial separation of the points on their two planes. The final contrast vector for each pair of samples was computed by taking the squares of the individual vectors, adding them, then taking the root of the sum. The resulting plots for the data given in Table L-3 are shown in Figures L-3 and L-4.

For example, the chromaticity vector for the green and yellow pavements would be determined by finding the vector (V_1) from the red-green chromaticity diagram ($V_1 = \sqrt{(0.56 - 0.34)^2 + (0.44 - 0.26)^2}$), and the vector ($V_2$) is calculated from the red-blue chromaticity diagram ($V_2 = \sqrt{(0.56 - 0.34)^2 + (0.22 - 0.18)^2}$). The final vector is $V = \sqrt{(V_1)^2 + (V_2)^2} = 0.372$.

Human Observation Tests

Use of the chromaticity vector provides a quantitative measure of color contrast. The development of such a measure is essential to the evaluation techniques prescribed for the analysis of delineations treatments in this project. However, the literature search failed to locate past research

TABLE L-3

AREA WITHIN EACH COLOR BAND FOR LUCALOX LIGHTING AND ALL NONBEADED PAVEMENT SAMPLES

TYPE OF SAMPLE	AREA UNDER COLOR BAND						
	RED	ORANGE	YELLOW	GREEN	BLUE	VIOLET	ALL
Red	0.339	0.206	0.087	0.166	0.139	0.063	1.00
Orange	0.373	0.218	0.079	0.157	0.120	0.053	1.00
Yellow	0.321	0.251	0.133	0.147	0.102	0.046	1.00
Green	0.230	0.182	0.101	0.295	0.144	0.048	1.00
Asphalt	0.301	0.226	0.110	0.175	0.140	0.048	1.00
PCC	0.353	0.203	0.065	0.177	0.144	0.058	1.00

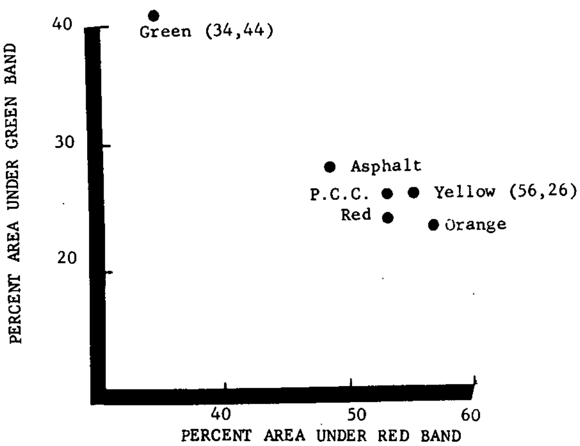


Figure L-3. Pavement sample plotted on red-green chromaticity diagram; Lucalox lighting.

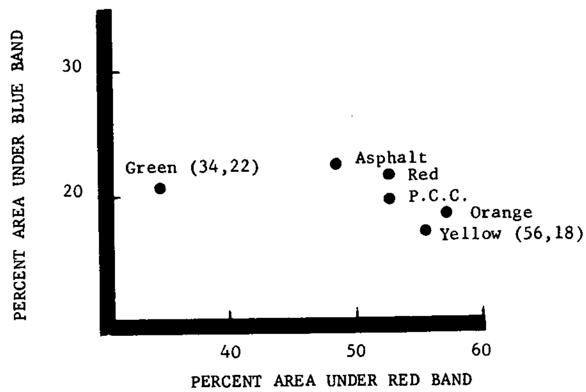


Figure L-4. Pavement samples plotted on red-blue chromaticity diagram; Lucalox lighting.

efforts that would verify this vector as a measure of the ease with which an individual can distinguish the difference between two colors. As noted previously, this appendix deals with a subjective interpretation that is as much psychophysical as physical. Thus, there was no assurance that a phenomenon measured in physical terms would accurately describe the total human response. Inasmuch as the interest was in interpretation and response, it was essential that tests be conducted on the validity of the measure prior to extensive experimentation on the combination of factors that change the spectral properties of the reflected lights.

The purpose of this phase of the project was to develop a scaling technique for use in determining potential candidate colored pavement treatments for use in delineation. The experiment with the human observer was therefore to provide data from which a correlation between the physical measure (chromaticity vector) and human response could be constructed. No attempt was made to search for an optimum measure, or to evaluate alternative measures of human response. The primary objective of the study was to quantify the physical properties of the reflected light, and continued work should be conducted on alternative measures of human response.

The measure of human response used in the experiment was the distance from which a subject could accurately identify the color and shape of two pavement samples exhibited side by side. The test stand used in the measurement of the spectral properties of the reflected light was modified to permit visual observation of the samples without the use of the instrumentation. The viewing angle was limited to the range from 1° to 8°, as it had previously been established that the spectral properties are essentially the same through this range.

Four pairs of colored pavement samples ranging from very low to very high vector lengths were placed in the test stand under each lighting condition. The samples were cut in different shapes and randomly placed on the test stand at a distance sufficient to assure that the subject could not determine the sample colors or the orientation. The subject was then asked to walk slowly toward the samples. The distances at which the subject accurately identified the shape and color of the samples were noted separately, and he was allowed to continue advancing until he had identified the complete set of samples. The lighting and the samples were changed and the same procedure was repeated until a data set was completed. A total of 15 observers was used in each experiment, with readings obtained for four samples under each of the lighting conditions.

The data were recorded as in Table L-4, and reduced to a common base, to account for differences in visual acuity, as in Table L-5. This procedure tends to mask the within-sample variance, but the data were not subjected to an analysis of variance and this technique provided data on the relative differences within each set of data points.

Preliminary data reduction and plotting revealed the relationship between color identification and shape identification, respectively, and the independent variable (vector length) to be the same. Therefore, the data points representing the distances at which the color was correctly identified were used in the final analysis.

The final data points for the 21 mean distances at which the color differences were accurately identified are shown in Figure L-5 plotted against the vector lengths calculated as described in the previous section.

A simple regression equation was derived using the least-squares technique, with the resultant equation: $y =$

TABLE L-4

DATA FORMAT USED TO RECORD DISTANCES AT WHICH COLOR WAS PROPERLY IDENTIFIED

	DISTANCE FOR SAMPLE COMBINATION[a]				
OBSERVER	1	2	3	4	ROW SUM
1	d_{11}	d_{12}	d_{13}	d_{14}	Σd_{1n}
2	d_{21}	d_{22}	d_{23}	d_{24}	Σd_{2n}
3	d_{31}	d_{32}	d_{33}	d_{34}	Σd_{3n}
⋮	⋮	⋮	⋮	⋮	⋮
m	d_{m1}	d_{m2}	d_{m3}	d_{m4}	Σd_{mn}

[a] Selected.

TABLE L-5

MATRIX FOR DETERMINING DISTANCE SCORE FOR USE IN REGRESSION EQUATION

OBSERVER	DISTANCE SCORE FOR SAMPLE COMBINATION[a] 1	2	3	4
1	$d_{11}/\Sigma d_{1n}$	$d_{12}/\Sigma d_{1n}$	$d_{13}/\Sigma d_{1n}$	$d_{14}/\Sigma d_{1n}$
2	$d_{21}/\Sigma d_{2n}$	$d_{22}/\Sigma d_{2n}$	$d_{23}/\Sigma d_{2n}$	$d_{24}/\Sigma d_{2n}$
⋮	⋮	⋮	⋮	⋮
m	$d_{m1}/\Sigma d_{mn}$	$d_{m2}/\Sigma d_{mn}$	$d_{m3}/\Sigma d_{mn}$	$d_{m4}/\Sigma d_{mn}$
Column ave. Score	0.247	0.199	0.282	0.271
Chromaticity vector length	12×10^{-2}	4×10^{-2}	32×10^{-2}	26×10^{-2}

[a] Selected.

$0.004v + 0.128$, with $r = 0.685$, where y is a measure of the distance at which the color could be differentiated and v is vector length times 10^{-2}.

The units for expressing y cannot be transformed directly into sight distance or any other measure of the physical situation, where the application of colored pavement would be considered. It is, instead, a measure of the relative distance that two colors can be differentiated, averaged over the range of visual acuity found in the subjects used in this study. The most important finding is the relative magnitude of the two constants in the regression equation (0.004 and 0.128). Because the magnitude of the slope is approximately 1/30th the magnitude of the constant, a change in vector length (v) of 10×10^{-2} will result in a 33 percent increase in the distance at which two colors can be differentiated.

The values of the chromaticity vector, as determined in the experimental work, were sufficient to describe a Δy of approximately 100 percent. Thus, however, the units of y might eventually be converted into the drivers' ability to discern differences. The magnitude of these differences can be produced in a ratio of 2 to 1 for the best and worst combination of colors and environmental conditions tested.

The results of this correlation analysis were satisfactory to warrant continued testing of the samples and verified the concept of the chromaticity vector as a measure of color contrast. Additional work would be required to completely validate the measure and to develop equations to translate the vector length into some measurable distances where the application of colored pavement is being considered.

The results of this experiment enabled continued testing of the colored pavements to determine the combinations of light source, pavement color, angle of vision, bead size, and environmental conditions that produce low-contrast and high-contrast values. Then, by pre-selecting these variables, one could produce a treatment that meets specified contrast values for field experimentation on delineation systems.

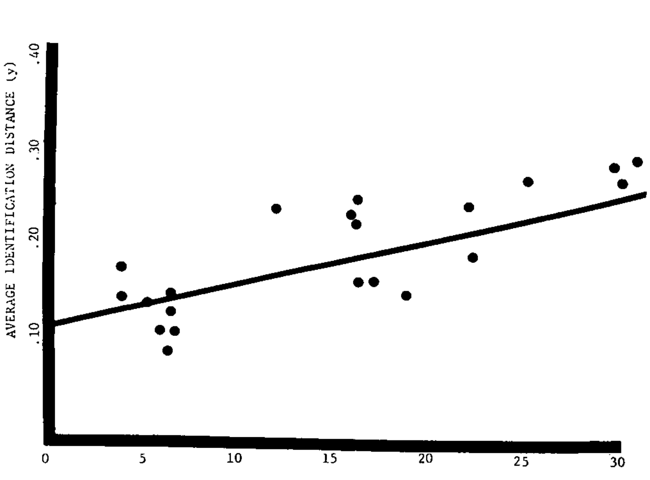


Figure L-5. Regression line for average distance at which the color combinations were correctly identified vs chromaticity vector.

Design of Experiment

The ideal laboratory experiment would be designed to test the effect of each value of the variables on the chromaticity vector. However, because there were five lighting conditions, six pavement types, eight sizes and types of reflective beads, three environmental conditions, and seven angles of incident light, this would result in 5,040 separate observations and records to describe the effect of all combinations without repetition.

The alternative design chosen was to investigate the effect of a single variable on the dependent variable and then select one or more values of this variable to fix as parameters in the next experiment in the sequence. This did not result in a complete set of data, but it did permit addressing specific questions and presenting the results in a few charts and graphs. This approach also resulted in certain efficiencies, because the chromaticity vector proved to be insensitive to some of the variables designated for testing.

There were two potential sources of error in the experiment, and it was considered essential to ascertain the magnitude of these errors prior to full experimentation. The first was in the variability of the samples used; the second, the viewing angle between the instrument and the horizontal. Preliminary tests were conducted on these two variables with fixed lighting striking the surface at 90°. Repetitive tests of this condition with different samples of the same pavement and of different points on the samples are shown in Figure L-6. It is apparent from these curves that the results of the experimental procedure are capable of being duplicated and that the dependent variable is constant for a given sample.

The viewing angle was then varied from 1° to 8° to represent the range of angles through which a driver might be required to view a colored pavement installation. Assuming a 3.75-ft eye height, this represents viewing distances varying from 214 ft to 27 ft. Once again the results proved to be insensitive to this variable. Because this was not one of the primary variables introduced into the study, the chromaticity vectors were not calculated; but the readings plotted in Figure L-7 illustrate the minor effect on the shape of the curve.

This was significant because it was necessary to change the sample stand between successive tests, and the viewing angle varied by ±1° between tests. This change did not occur within a given test series, but some observations are made later in the study based on the results of different test series. Thus, it is important to realize that a minor change in the viewing angle would not seriously affect the results.

An angle of 4° was chosen for the tests because this provided a safe margin of error in both directions.

A series of tests was then conducted to produce the chromaticity vector lengths necessary to describe the potential for colored pavements to be used as a delineation treatment. The first tests were conducted to determine the combination of light source and color combinations that produced the maximum vector lengths.

These combinations were then selected for the remaining test series to determine the deterioration of the vector lengths as the test conditions were changed. The effect of varying the angle of incident light was the first such change in the test conditions.

Next, to obtain the visual characteristics of the colored samples under different environmental conditions, the same tests were carried out with wet samples; i.e., with a thin film of water on the samples, as well as with about 1/16 in. of water standing on them.

Further, it was necessary to determine the nature and the rate of change of the visual characteristics of the samples under the natural process of wearing and weathering. The samples were subjected to accelerated wear and weather tests and the observations were repeated in increments.

Finally, beaded samples using both clear and colored beads of different sizes were used for testing whether the addition of beads made a positive contribution toward improving the visual characteristics of the samples under automobile headlighting.

Results

Light Source

The four light sources most commonly used for street lighting, as well as automobile headlights, were tested to determine their effect on the various pavement surfaces. Inasmuch as light source was an independent variable in this study, the experiment was conducted on all pavement samples and the spectral distribution curves were plotted for further analysis.

No effort was made to control the intensity of various light sources incident on the test samples because the primary interest was in evaluating the contrasts between pairs of samples under given lighting conditions. All six pavement types were tested for all four light sources. It was found that the effect of auto headlamps together with fixed lighting was not different from that with the fixed light source alone. This is probably attributable to the fact that the intensity of the auto headlamp was small compared to the high-efficiency light sources being focused on the sample from a short distance.

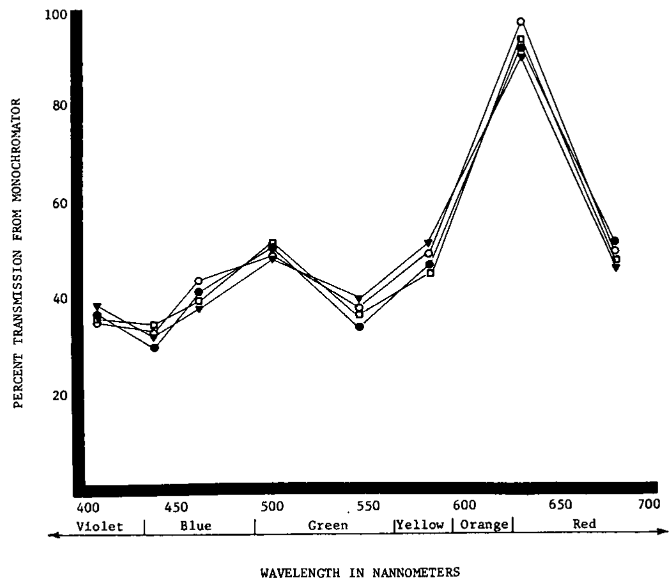


Figure L-6. Examples of repetitive measurement of a spectral curve; red-beaded pavement with Lucalox lighting.

The results of this analysis are presented in Table L-6, where the color combinations that produce the maximum contrast are recorded under each lighting type. These results can be used to select the color combination that is most effective under a specified light source. Conversely, the results can be used to select the best type of overhead lighting for a specified color combination being considered for installation as a delineation treatment.

The table shows that the combination that can be distinguished at the greatest distance is orange and green pavement installed under Lucalox lighting. The worst combination is orange and red pavement under Lucalox

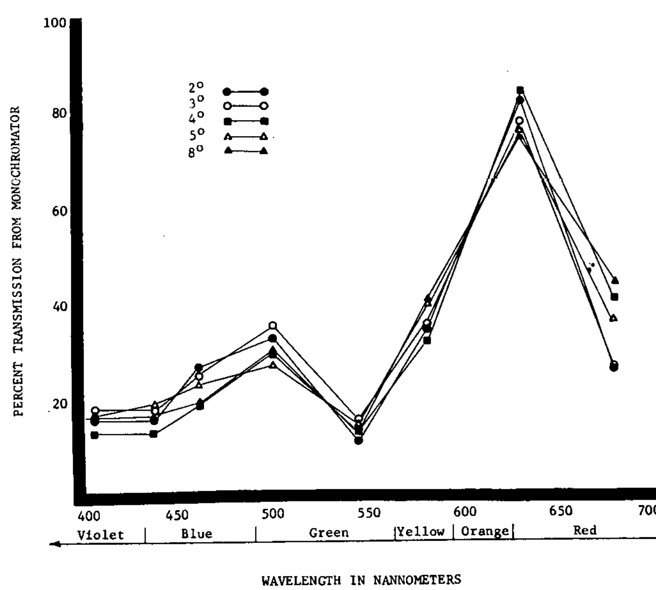


Figure L-7. Spectral distribution of light for various angles of reflectance.

TABLE L-6

MAXIMUM VECTOR LENGTHS AS DETERMINED FROM THE COMPARISON OF ALL SAMPLE COMBINATIONS UNDER EACH LIGHTING CONDITION

	MAXIMUM VECTOR LENGTH UNDER							
	LUCALOX		MERCURY VAPOR		FLUORESCENT		INCANDESCENT	
SAMPLE	COLOR	VALUE	COLOR	VALUE	COLOR	VALUE	COLOR	VALUE
PC concrete	Green	0.324	Yellow	0.221	Yellow	0.224	Yellow	0.110
Asphaltic concrete	Green	0.267	Yellow	0.220	Yellow	0.220	Orange	0.164
Red pavement	Green	0.329	Yellow	0.224	Yellow	0.216	Yellow	0.117
Orange pavement	Green	0.383	Green	0.262	Green	0.330	Green	0.164
Yellow pavement	Green	0.362	Green	0.306	Green	0.354	Green	0.223
Green pavement	Orange	0.383	Yellow	0.306	Yellow	0.354	Yellow	0.223

lighting. The difference in the chromaticity vector is sufficient to produce a ratio of 1.91 to 1. Because these are two variables often considered in the treatment of a specific high-accident location, this information may contribute to the ultimate success of those projects that include delineation as a treatment.

Incident Angle

It was recognized in the design of the experiment that the angle of incidence of a fixed light source is a continuous variable that may affect color perception by the observer. The color of the incident light source and the reflecting surfaces will determine at what angle the color of the reflected light is masked by the direct light.

Observations were taken on the pavement samples with all five light sources from 90° to 40° angles of incidence in increments of 10°, or until the spectral distribution curves represented the color spectrum of the incident light. The testing was stopped when the spectral distribution curves of different colored samples produced the same or similar spectral curves. The results of this test are given in Table L-7. It is apparent that the angle of incidence is critical to the ability to discern differences in color.

Past studies have concluded that the driver cannot see colored pavement installations under headlights, and the installations were considered unsatisfactory where they must convey a message under both day and night conditions. Inasmuch as headlights are always at a low incidence angle, the results of this test substantiate these previous deductions.

TABLE L-7

EFFECT OF INCIDENCE ANGLE ON AREA MEASUREMENTS UNDER THE NORMALIZED CURVE AND YELLOW-ORANGE CHROMATICITY VECTOR UNDER LUCALOX LIGHTING

INCIDENCE ANGLE (DEG)	PAVEMENT SAMPLE COLOR	NORMALIZED AREA UNDER			CHROMATICITY VECTOR
		RED	GREEN	BLUE	
90	Green	0.229	0.292	0.144	0.383
	Orange	0.371	0.157	0.120	
70	Green	0.298	0.208	0.156	0.191
	Orange	0.376	0.156	0.130	
60	Green	0.275	0.196	0.134	0.147
	Orange	0.359	0.166	0.132	
50	Green	0.300	0.202	0.156	0.079
	Orange	0.319	0.175	0.139	

Wet and Dry

The applicability of the delineation treatments under various environmental conditions was specified as one of the objectives in the original research statement. The only environmental condition to be tested in this phase of the project was the effect of rain on the value of the contrast measure. Once again, previous studies have indicated this to be a problem.

To test whether the depth of water on the surface would influence the color perception, each pavement sample was tested with surface-wet condition and with a 1/16-in. water film. Spectral curves were constructed after each observation and the vector calculation was completed.

The results of these tests are shown in Figure L-8. The deterioration of the color with surface water is apparent. The existence of the water film causes the direct light to be reflected into the recorder, and the differences between the surface types are lost. In the same fashion, the driver is faced with reflected light from the water surface, and it is impossible to discern differences in colored pavements when there is sufficient rainfall to produce a water film.

During installation, samples were removed from the surface and one sample of each color was placed in the accelerated weathering chamber at PennDOT. This chamber, equipped with an ultraviolet light source and a capability to add moisture to the samples, can simulate the normal weathering cycle at an increased rate.

The samples were tested to determine the chromaticity vector prior to placing them in the chamber, and again after a simulated six-month exposure to sun and rain conditions. Chromaticity vectors were calculated to determine the incremental loss from extended exposure. Each of the color combinations was tested for each of the four light sources with an average reduction of 30 percent in the chromaticity vector. These changes varied from a low of 10 percent to as high as 55 percent reduction.

The variance in the results of the exposure confirms the belief that the ability of colored pavements to retain their usefulness is seriously impaired by weather fading, and that the rate at which the loss of color occurs is a function of the pigmentation.

An accelerated wear test was conducted on an equal sample of cores removed from the field applications of the colored pavements. However, the testing procedure, which consisted of a weighted tire revolving about a central axis with a relatively tight radius, deposited a layer of rubber on the samples. This prevented obtaining meaningful values of the effect of wear on the chromaticity vector.

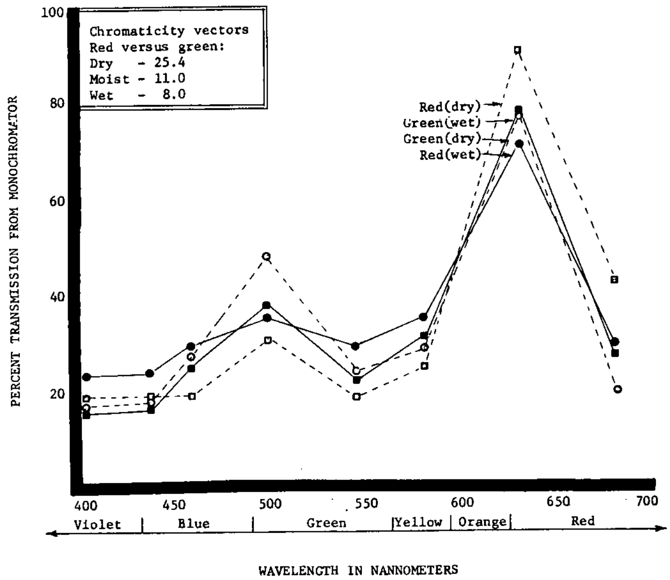


Figure L-8. Spectral distribution of green and red (wet and dry) pavement reflectance from Lucalox lighting.

Surface Treatment

The surface treatment experiment was designed to determine the effect of glass beads on the reflective properties of the colored pavement samples. This test was conducted with the auto headlamp as the only light source, under dry surface conditions, and on all colored pavement samples. The portland cement concrete and asphaltic concrete samples were not included in this study. The auto headlamp was considered the most useful source of light in this test because the situations where the beads might be applied on pavement surfaces are isolated locations devoid of fixed lighting. The question of interest in this study was whether the glass beads could be used to obviate the need for fixed lighting and still produce an acceptable chromaticity vector between two colors.

The effectiveness of the beads is dependent on the color of the beads, as shown in Figure L-9. The reflected light from colored bead samples (chromospheres) produces a much greater area under their respective color bands than do the clear beads. However, even the use of this bead type results in the reflected light being composed primarily of the spectral properties of the incidence light.

The chromaticity vector for the red and yellow pavements was calculated to determine the relative effectiveness attainable through surface treatment. The maximum vector length (0.125) is significantly less than that observed under certain street lighting conditions for these two colors (0.216).

Conclusions

The evaluation of colored pavements as a delineation technique has been complicated by the lack of a method for separating the effects of the low level of stimulus and the driver response to this stimulus. Most other delineation treatments—painted lines, post-mounted delineators, rumble strips, and raised markers—are conceded the capability of producing stimulus beyond the minimum threshold required by the driver. However, the lack of success in past installations of colored pavement is at least partially attributed to the lack of stimulus, particularly at night and under adverse weather conditions. Because of certain advantages of this treatment, including (a) the potential for areal application, (b) the possibility of locating the treatment directly in the driver's line of vision, and (c) the potential for including the dimension of color coding to delineation, it was decided that this study of the stimulus potential would be conducted. The study results were to be used in the design of field tests to evaluate driver response to this treatment.

Within this framework, the following conclusions were reached:

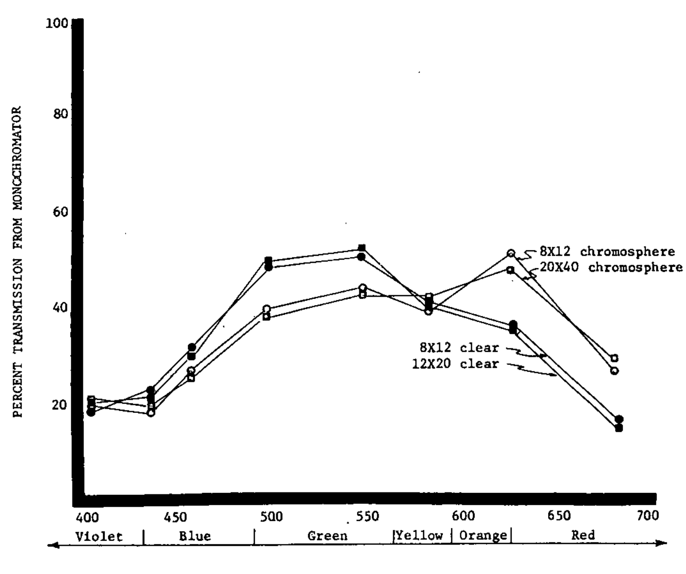


Figure L-9. Spectral distribution of headlight reflection from clear beads and chromosphere beads on red pavement sample.

1. The spectral distribution of light reflected from the pavement surface can be used to define a measure of color contrast between two samples. This measure has been defined as the "chromaticity vector."

2. The data required to define the chromaticity vector can be reproduced consistently and are stable through viewing angles from 1° to 8° at least.

3. There is a correlation between the chromaticity vector and the ability of a subject to differentiate colors.

4. The selection of color and lighting conditions can be used to produce changes of 100 percent in the distance at which colors can be correctly differentiated.

5. The chromaticity vector approaches zero as a water film is formed on the pavement. This is caused by the reflected light containing the characteristics of the incident light and not the reflecting surface of the pavement.

6. The use of low-angle lighting, including headlights, causes a rapid deterioration of the chromaticity vector length. For a single overhead light, the critical angle is approximately 70°.

7. The addition of chromosphere beads to the surface of the pavement produces color contrast under automobile headlights. However, the maximum contrast is well below that attainable with overhead lighting. The use of clear beads produces brightness, but not color contrast, under automobile headlighting conditions.

8. The ability of colored pavements to retain their usefulness is seriously impaired by weather fading.

APPENDIX M

COMPARISON OF DELINEATION TREATMENTS ON A TWO-LANE RURAL HORIZONTAL CURVE *

PURPOSE OF STUDY

Present delineation treatments for rural roads consist mainly of standard pavement markings and post-mounted delineators. With few exceptions, the use of raised pavement markers (RPM's) has been restricted to multilane highways.

In reviewing the literature on delineation, it was found there have been no reported studies comparing different delineation treatments for rural roads. Although there have been post delineator studies that evaluated their absence versus their presence, none of the studies reviewed examined the effects of varying the installation pattern, or compared post delineators to other delineation devices. Also, to date, there have not been any reported studies on RPM's for rural highways.

The objective of this study was to compare the effect that three delineation treatments (paint markings, post delineators, and raised pavement markers) have on traffic behavior. The comparison method was used to determine if any particular treatment, or combination of treatments, provides better delineation, based on field measures of traffic performance.

The study was divided into two phases. In the first phase, six patterns of post delineators and a null case were tested. In the second phase, two patterns of RPM's, one pattern of post delineators, and a freshly painted centerline were compared. Nighttime vehicle speed and lateral placement data were collected for all test patterns.

* By Robert E. David, Research Assistant, The Pennsylvania State University.

SCOPE

A 1.6-mile section of Pa. 144 between Pleasant Gap and Bellefonte, Pa., was selected as the test section. The selected location was studied under the following delineation configurations:

Phase 1

1. No delineators.—In this case no delineators were placed along the roadway for traffic guidance.

2. Right edge only.—Crystal delineators were placed along the right edge of the roadway in the direction of travel.

3. Both edges, crystal.—Crystal delineators were placed along the left and right edges of the roadway in the direction of travel.

4. Both edges, amber and crystal.—Crystal delineators were placed along the right edge; amber delineators along the left edge in the direction of travel.

5. Outside of curve, crystal.—Crystal delineators were placed along the right edge of the roadway except at right curves. At right curves the delineators were placed on the left edge of the roadway.

6. Outside of curve, revised spacing.—This pattern was the same as No. 5 except that the spacing between the delineators was doubled.

7. Outside of curve, amber.—This pattern was the same as No. 5 except that amber delineators were placed along the left edge of the roadway at right curves.

Phase II

8. Raised pavement markers and post delineators.—Yellow RPM's were placed to simulate a single center line and the post delineators were placed as in No. 7.

9. Raised pavement markers.—The post delineators were covered and the RPM's were left in place.

10. Freshly painted center line.—The RPM's were removed and reflectorized yellow paint was applied for the center line.

11. Freshly painted center line and post delineators.—Post delineators as described in No. 7 were added to the paint line.

Within the test section two consecutive curves were studied. For each of the treatment conditions speeds through the entire curve and vehicle placement within the curve were collected for traffic in both directions. All data were collected at night and in good weather conditions.

TEST LOCATION

Through consultations with officials of the Pennsylvania Department of Transportation (PennDOT) and examination of State Police accident pin maps, several roads were selected as possible sites. After reviewing the PennDOT accident records, a 1.6-mile section of Pa. 144 between Pleasant Gap and Bellefonte, Pa., was selected as the test section. This road is part of Pennsylvania's secondary highway system. Development along the road in the area of the test section includes houses, barns, a fertilizer plant, and a State fish hatchery. However, most of these structures are far enough off the road so that they provide the driver with little, if any, delineation information.

Within the test section there are 33 changes in horizontal alignment. The road contains many compound and reverse curves. The radius of curvature for these curves varies from 207 ft to 1,910 ft, with the length of curve varying from 95 ft to 250 ft. The longest tangent section is 810 ft. The width of the bituminous pavement ranges from 18 to 20 ft. A gravel shoulder, 2 to 3 ft wide, exists along both sides of the roadway. Changes in vertical alignment are negligible.

PennDOT accident records show a total of 22 nighttime accidents on this roadway section in the 1966-68 period. It is possible that poor delineation was a contributing factor in 17 of these 22 accidents. The following types of accidents were considered potentially delineation-related: run-off-the-road, head-on, and opposite direction side swipe.

Two curves were selected as study sites. The horizontal geometrics of these curves are shown in Figures M-1 and M-2. PennDOT accident records indicate that five nighttime accidents occurred at Curve 1 from 1966 through 1968, whereas Curve 2 had one nighttime accident during the same period. Poor delineation may have been a factor in all six of these accidents. The delineation on both of these curves when the study was initiated consisted of a weathered painted center line. On Curve 1, in addition to the center line, eight double yellow post delineators spaced 8 ft apart had been installed to help delineate the curve in the Bellefonte direction. The ends of the small bridge located on the Curve 1 section were marked with black-and-white paint stripes. However, the abutments were extremely dirty and the stripes were hardly noticeable at night.

DELINEATION INSTALLATION

Post Delineators

The installation of the post-mounted delineators was designed according to PennDOT specifications, which state that maximum delineator spacing will be based on the formula:

$$S = 2\sqrt{R} \qquad \text{(M-1)}$$

in which

S = delineator spacing, in ft; and
R = center-line curve radius.

On compound curves the specified delineator spacing for the smaller-radius curve was used throughout the entire compound curve, provided the specified spacing for the larger-radius curve was less than 25 percent greater than that for the smaller-radius curve. This arbitrary rule greatly simplified designing the delineator spacing layout.

The delineators used for the experiment were the 3-in., circular, retroreflective type used by the Pennsylvania Department of Transportation. Depending on the test pattern, they were either crystal or amber in color.

Raised Pavement Markers

At each test curve a different RPM type was used. Within Curve 1 a low-intensity reflective marker (see Fig. C-8, App. C) was placed on 4-ft centers. This type of marker is designed for both day and night delineation, and at this spacing adequately simulated a solid yellow center line (Fig. M-3). Within Curve 2 a combination of the previously mentioned marker (without the glass reflectorized beads) and a high-intensity reflective marker (see Fig. C-7, App. C) was used. The markers within the second curve were placed on 4-ft centers with a reflective marker placed every 24 ft. This pattern also provided adequate simulation of a solid center line both day and night (Fig. M-4).

EXPERIMENTAL PROCEDURE

Instrumentation

The major portion of the data collection equipment used in this study was obtained on loan from the Federal Highway Administration. The major components of the speed profile data acquisition system consisted of a series of light source/photoelectric detector pairs, a data monitor control unit, and a strip-chart recorder. The source/detector pair acts as a switch; open when the light beam across the highway is uninterrupted and closed when the light beam is broken. Eleven pairs of sources and detectors were used at each test site. Pairs 1 through 9 were spaced at 100-ft intervals and were used to record the vehicle's successive arrival times through the trap. (Speeds could then be calculated.) Pairs 0 and 10 were used to trigger the recorder when a vehicle was about to enter the test section. The

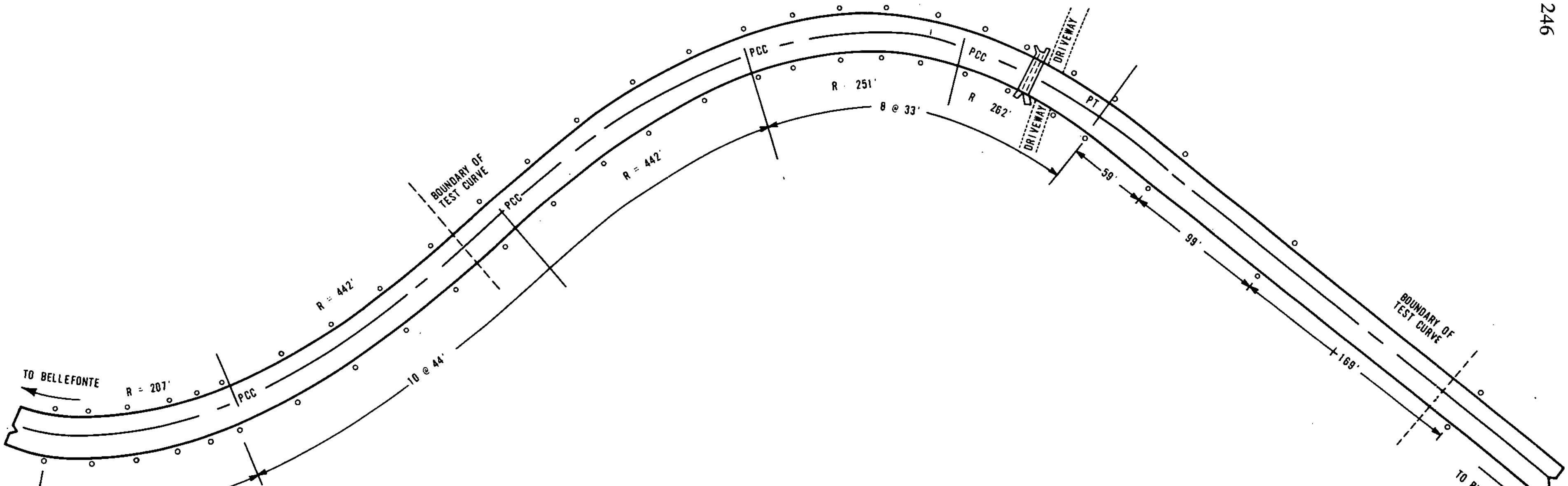


Figure M-1. Curve 1; horizontal geometry and delineator spacing.

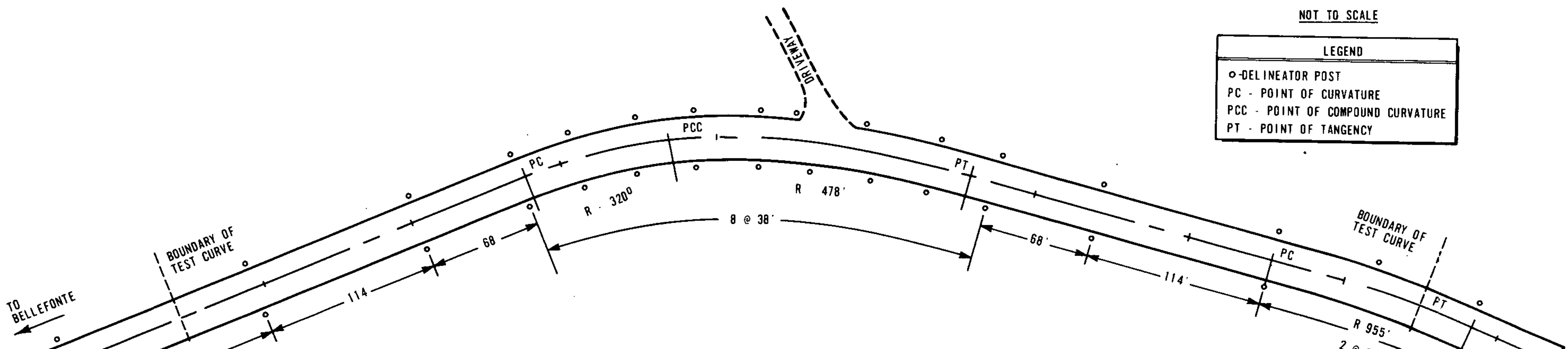
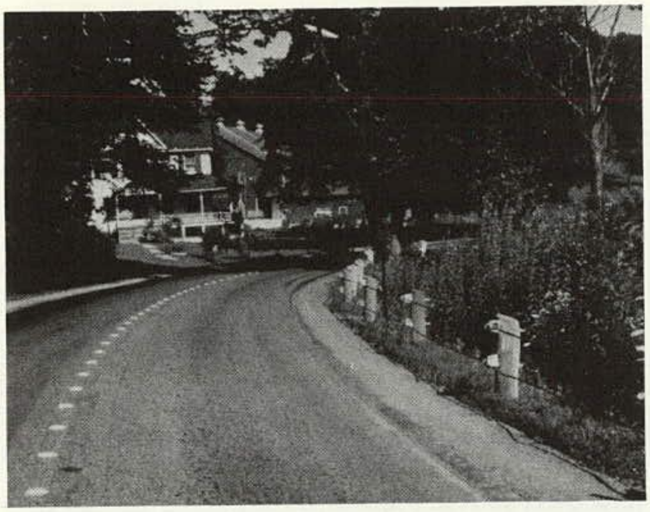


Figure M-2. Curve 2; horizontal geometry and delineator spacing.



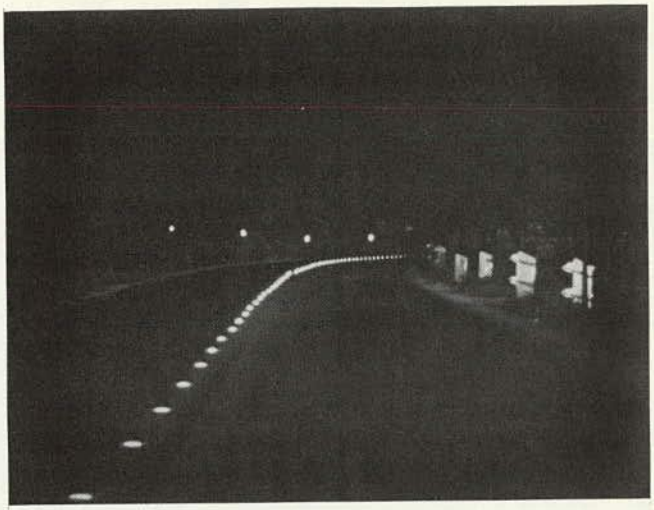


Figure M-3. Day and night views of low-intensity raised pavement markers for center line of curve 1.

data monitor control unit activated the correct stylus in the recorder as the light beams were broken. A 100-channel electric writing event recorder was used to record the input signals from the detectors.

The lateral placement data acquisition system consisted of a placement tape and a 20-pen recorder. The tape detects the lateral location of the vehicle's wheels, to the nearest foot, as they cross the tape. It consists of 20 separate electrical circuits with a switch in each circuit. As a vehicle's tires pass over the tape the switch is closed and the electrical circuit is completed.

Data Collection

The placement tape was set up at the center of each curve. Detectors 5 and 6 were then located 50 ft on each side of the tape. The other detectors were placed at 100-ft intervals from 5 and 6.

Only free-flowing, two-axle vehicles (such as passenger cars and pickup trucks) were recorded. For speed data purposes, a free-flowing vehicle was defined as one that, upon entering the test section, was not following another vehicle in the same direction by a headway of less than 7.5 sec, and did not meet an oncoming vehicle in the middle 400 ft of the test section. A free-flowing vehicle for placement data purposes was defined as one that did not follow another vehicle going in the same direction by less than 5 sec or encounter an oncoming vehicle within 5 sec after crossing the placement tape.

Data collection for each treatment at each curve was completed in one night between the hours of 9 and 12 PM. Approximately 50 free-flowing vehicles were recorded for each direction. Data were collected only on weekday nights (Monday through Thursday). Test patterns were changed on Friday of each week.

A vehicle's average speed within each of eight 100-ft intervals was determined at each curve for each treatment. The vehicle's average speed through the entire test curve was determined by averaging the speed through the eight intervals. A grand mean speed for each treatment was then obtained by calculating the mean of all the vehicle mean speeds. A trap mean speed was also determined from the speed data on all the vehicles traversing each 100-ft interval. Standard deviations for each of the eight trap means and the grand mean were also computed. By way of an example, Table M-1 gives the trap mean speeds, grand mean speed, and standard deviations for Phase 1 at one study location.

For each treatment situation, the mean distance (and the standard deviation) from the vehicles' left wheels to the center line was calculated.

Discussion of Results

The traffic engineer often compares vehicle speeds and/or placements before and after an installation to evaluate improvements. These results are often statistically significant, but difficulty arises in interpreting them from a

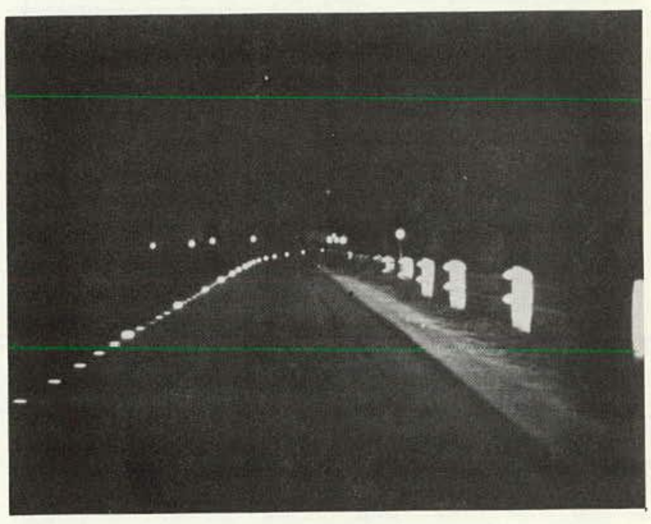


Figure M-4. Night view of high-intensity reflective markers with nonreflective markers for center line of curve 2.

TABLE M-1

MEAN SPEEDS AND STANDARD DEVIATIONS FOR PLEASANT GAP-BOUND VEHICLES ON CURVE 2

TREATMENT	NO. OF OBS.	SPEED (MPH) TRAPS 1–2 MEAN	STD. DEV.	TRAPS 2–3 MEAN	STD. DEV.	TRAPS 3–4 MEAN	STD. DEV.	TRAPS 4–5 MEAN	STD. DEV.	TRAPS 5–6 MEAN	STD. DEV.	TRAPS 6–7 MEAN	STD. DEV.	TRAPS 7–8 MEAN	STD. DEV.	TRAPS 8–9 MEAN	STD. DEV.	GRAND MEAN MEAN	STD. DEV.
Phase I																			
1. No delineators	43	41.7	6.02	39.6	5.36	39.2	4.84	37.5	4.06	37.5	4.30	36.9	3.98	37.7	4.32	38.5	4.38	38.6	4.31
2. Delineators, right edge	60	39.8	5.49	37.6	5.76	38.3	5.68	36.4	5.13	36.5	5.00	35.8	5.73	37.2	5.08	38.1	5.86	37.5	5.17
3. Delineators, both edges, crystal	52	40.3	5.63	39.1	5.40	38.1	5.06	35.6	5.32	37.5	5.25	37.2	5.73	39.2	5.64	39.9	5.98	38.5	5.21
4. Delineators, both edges, amber and crystal	62	37.8	4.81	36.9	4.34	35.9	4.77	34.8	4.37	34.7	4.89	34.8	4.91	35.3	4.70	37.1	4.86	35.9	4.43
5. Delineators, outside of curve, crystal	46	40.0	5.80	37.6	5.44	36.3	4.99	35.7	5.28	34.7	4.96	34.8	4.89	36.0	5.31	37.0	5.48	36.5	4.91
6. Delineators, revised spacing	55	40.3	4.81	38.4	4.81	37.6	4.33	37.5	4.40	35.7	4.64	35.6	4.43	36.9	4.51	37.9	4.41	37.5	4.15
7. Delineators, outside of curve, amber	65	40.8	6.60	39.2	6.03	38.5	5.44	37.4	5.70	36.1	6.14	35.7	6.20	37.9	6.69	39.6	6.77	38.0	5.93

practical standpoint. Perhaps the solution is in reexamining the primary goal of the research—making the highway system safer by reducing the number of accidents. Michaels (*118*) states that 60 to 80 percent of all traffic accidents may be due to random errors resulting from variability in the system. By minimizing the variability, fewer random errors, and as a result fewer accidents, will occur.

By interplaying and optimizing the vehicle's performance characteristics and the highway's geometry, the ideal path for a particular vehicle and section of roadway can be defined. In theory, the elimination of all variability in the driver-vehicle-highway system would result in all vehicles following the same line of travel at the same speed on a roadway; thus, the ideal path would be achieved, and no accident would occur. Although this ideal situation would probably never be achieved, the goal of making the system safer can be reached by implementing a technique that reduces the variability of the system. This assumption was followed in analyzing the data from this experiment. (For a more detailed discussion, see Appendix T.)

Data Summary

Vehicular Speed

The sample means and standard deviations for vehicle speeds are summarized in Table M-2. The mean speed is the average of all vehicle speeds over the eight 100-ft speed traps.

The data for speeds appear to be homogeneous across all treatments for each of the four situations. For Curve 1 in the direction of Bellefonte the mean speeds ranged from 30.9 to 32.1 mph; in the direction of Pleasant Gap, from 30.1 to 32.6 mph. For Curve 2 in the direction of Bellefonte the mean speeds ranged from 35.3 to 37.9 mph; in the direction of Pleasant Gap, from 35.5 to 38.6 mph. The only trend that is evident is for Pattern No. 4 (delineators, both edges, amber/crystal), where the mean speeds were consistently lower when compared to the other patterns in each situation.

Lateral Placement

The sample mean and standard deviation for the vehicles' lateral placements within the lane are summarized in Table M-3. The mean distance is measured from the vehicles' left wheels to the center line.

Table M-3 indicates that in almost every case the base condition (no delineators, and a weathered center line) produced a mean lateral placement closest to the center line. Also, the data indicate that when raised pavement markers were present (treatments 8 and 9) the mean distance was farthest away from the center line. Statistical analyses of the mean placements were not performed to determine the significance of these observations; emphasis was placed on changes in the variance.

Results in Variance Analysis

The principal parameters used for effectiveness evaluation were the variances (square of the standard deviation) of both speeds and vehicle lateral placements. If a significant reduction in the variance (determined by a statistical

TABLE M-2

TREATMENT GRAND MEAN SPEEDS AND STANDARD DEVIATIONS

TREATMENT	SPEED (MPH)							
	CURVE 1				CURVE 2			
	TO BELLEFONTE		TO PLEASANT GAP		TO BELLEFONTE		TO PLEASANT GAP	
	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Phase I								
1. No delineators	31.5	3.22	32.5	3.56	37.0	3.65	38.6	4.31
2. Delineators, right edge	31.4	3.48	31.2	3.00	36.6	3.81	37.5	5.17
3. Delineators, both edges, crystal	31.3	3.84	30.5	3.84	37.0	5.05	38.5	5.21
4. Delineators, both edges, amber and crystal	30.9	3.75	30.1	3.39	35.8	4.85	35.9	4.43
5. Delineators, outside of curve, crystal	31.4	3.31	31.0	2.88	37.9	5.29	36.5	4.91
6. Delineators, revised spacing	31.4	4.09	31.9	2.82	37.2	4.67	37.5	4.15
7. Delineators, outside of curve, amber	32.1	3.14	31.3	3.51	36.9	4.28	38.0	5.93
Phase II								
8. RPM's and delineators	31.0	3.37	31.6	3.22	35.3	4.80	35.5	3.85
9. RPM's only	31.4	3.59	31.5	3.76	36.1	4.41	35.8	4.41
10. Painted center line	30.9	3.07	32.1	3.60	35.7	4.10	37.2	5.21
11. Painted center line and delineators	30.9	3.43	31.4	3.37	36.5	4.83	36.0	4.51

TABLE M-3

MEAN LATERAL PLACEMENT AND STANDARD DEVIATIONS OF VEHICLES' LEFT WHEELS FROM CENTER LINE

TREATMENT	PLACEMENT (FT)							
	CURVE 1				CURVE 2			
	TO BELLEFONTE		TO PLEASANT GAP		TO BELLEFONTE		TO PLEASANT GAP	
	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Phase I								
1. No delineators	0.2	1.89	1.6	1.34	1.0	1.56	1.5	1.12
2. Delineators, right edge	0.9	1.56	1.7	1.31	1.2	1.40	1.7	1.80
3. Delineators, both edges, crystal	0.7	1.94	1.7	1.12	1.4	1.26	1.6	1.02
4. Delineators, both edges, amber and crystal	0.6	1.72	1.7	1.05	1.8	1.43	1.8	0.80
5. Delineators, outside of curve, crystal	1.0	1.52	1.8	1.25	1.5	1.81	1.6	1.25
6. Delineators, revised spacing	1.1	1.72	1.7	1.31	0.8	1.50	1.5	1.02
7. Delineators, outside of curve, amber	0.4	2.07	1.4	1.42	1.3	1.17	1.3	0.86
Phase II								
8. RPM's and delineators	2.6	0.74	2.2	0.99	2.7	0.79	2.2	0.73
9. RPM's only	2.7	0.81	2.2	0.80	2.7	0.81	2.2	0.79
10. Painted center line	1.7	1.14	1.7	1.01	1.5	0.94	1.7	0.87
11. Painted center line and delineators	2.2	0.91	2.1	0.88	1.6	0.86	2.1	0.79

F-test) is noted between two delineation treatments, it is postulated that the treatment with the lower variance is better.

Table M-4 is the summary of the results of the *F*-tests used to compare the several treatments. The table is presented as a series of questions designed to determine if a higher level of delineation improves driver performance (i.e., reduces the variance). If the variance (speed or lateral placement) was reduced, the answer to the question is noted as "yes"; conversely, if the variance increased, the answer is "no." A dash (—) indicates that there was no statistically significant difference between the two treatments.

Question 1—Are any of the post delineator patterns better than the no delineator pattern?

Phase I of this study was designed to ascertain if any particular post delineator pattern improves driver performance. Thereafter, each of the six patterns was compared to the base condition—Pattern 1, or No Delineators. From Table M-4 it appears that none of the post delineator patterns consistently reduced the variance; nor was the variance increased. Treatment 4 (both edges, amber/crystal) showed an improvement in the lateral placement variance at two locations; whereas the speed variance increased at one location. All other patterns showed no consistent trend of improvement. Thus, it seems that none of the post delineator patterns had any beneficial effect, in terms of reducing speed or lateral placement variance.

Question 2—Is a freshly painted center line better than a weathered center line?

From Table M-4, it can be seen that presence of a freshly painted center line had no effect on the variance of the vehicle speeds when compared to the base condition. However, when lateral placement is considered the variance improved with the presence of the newly painted center line in every situation. This result substantiates the logical assumption that a continuous center line acts as a reference point to guide the motorist.

Question 3—Are post delineators and a freshly painted center line better than painted center line only?

This comparison is made to determine if the addition of post delineators (Pattern 7) helped to further reduce the variance. Again referring to Table M-4, a reduction in lateral placement variance occurred at only one location. It is significant that variance was not increased for either speed or lateral placement at any situation. The data indicate that, at best, there is only a marginal improvement when post delineators are added to freshly painted center lines.

TABLE M-4

COMPARISON OF DELINEATION TREATMENTS

	VARIANCE REDUCED [a]							
	CURVE 1				CURVE 2			
	SPEED VARIANCE		LAT. PLACE. VARIANCE		SPEED VARIANCE		LAT. PLACE. VARIANCE	
QUESTION	BELL.	P. GAP	BELL.	P. GAP	BELL.	P. GAP	BELL.	P. GAP
1. Post delineators only better than weathered center line?								
(a) Rt. edge, crystal	—	—	—	—	—	—	—	—
(b) Both edges, crystal	—	—	—	—	No	—	—	—
(c) Both edges, amber/crystal	—	—	—	Yes	No	—	—	Yes
(d) Outside, crystal	—	—	—	—	No	—	—	—
(e) Revised spacing	—	Yes	—	—	No	—	—	—
(f) Outside, amber	—	—	—	—	—	No	Yes	—
2. Freshly painted center line better than weathered center line?	—	—	Yes	Yes	—	—	Yes	Yes
3. Post delineators and freshly painted center line better than painted center line only?	—	—	Yes	—	—	—	—	—
4. Are RPM's better than weathered center line?	—	—	Yes	Yes	—	—	Yes	Yes
5. Are RPM's better than new center line?	—	—	Yes	Yes	—	—	—	—
6. Are RPM's and post delineators better than new center line and post delineators?	—	—	Yes	Yes	—	—	—	Yes

[a] — = No statistically significant difference.

Question 4—Are raised pavement markers better than a weathered center line?

The results of this comparison are similar to those of Question 2. An improvement in the lateral placement variance was noted in all four situations, whereas the speed variance showed no statistical change. Again, it appears that the center line, in this case provided by raised pavement markers, acts as a continuous guide for the motorist.

Question 5—Are RPM's only better than a freshly painted center line?

As in almost every other comparison, speed variance is not affected. However, a reduction in lateral placement variance was noted for both directions at Curve 1 when raised pavement markers were used. It should be noted that Curve 1 was more severe than Curve 2.

Question 6—Are RPM's and post delineators better than a new center line and post delineators?

The final comparison made is that of raised pavement markers with post delineators against freshly painted center line and post delineators. Once again, no change was noted for the speed variance in any of the four situations. The placement variance did improve at three locations, however. It would appear, then, that the presence of raised pavement markers is the principal factor for the reduced variance.

Conclusions

The conclusions of this study are summarized as follows:

1. Vehicular speeds are an insensitive measure for evaluating various delineation patterns on horizontal curves. The mean speeds and the variances did not change appreciably from one pattern to another. It appears that an alteration in delineation practices will not change vehicular speeds through the curve.
2. Vehicular lateral placement, especially the variance, proved to be a sensitive measure of driver performance. For many situations a statistical change was noted in the variance of the lateral placements.
3. Driver performance, in terms of speed and lateral placement within the curve, was not significantly affected solely by the presence or absence of any of the six patterns of post delineators.
4. An improvement in driver behavior (reduced variance) was noted when the freshly painted center line was compared to the base condition of a weathered center line and no delineators.
5. A marginal improvement (over the new center line treatment) in driver behavior occurred with the presence of raised pavement markers.
6. A delineation pattern of raised pavement markers and post delineators displayed improved driver performance (reduction in lateral placement variance) when compared to a new center line and post delineators.

An inherent objective of this study was to provide recommendations on which the traffic engineer could formulate delineation warrants or choose a delineation treatment(s) for two-lane rural highways. In Phase I, six post delineator patterns were evaluated and compared against a base condition of no delineators and a weathered center line. With only a few of the study parameters changing significantly, no trend was obvious to indicate that any of the post delineator patterns improved driver performance.

Which of the post delineator patterns, if any, should the traffic engineer choose? Inasmuch as the data collected do not provide any basis for selection, a subjective evaluation is necessary. Other studies have indicated that the presence of reflective post delineators has reduced accidents; therefore, it would seem worthwhile to use delineators on curved sections. On the basis of personal preference, the researchers would recommend a combination of Patterns 6 and 7. (For Pattern 6 crystal delineators were placed with an increased spacing of $4\sqrt{R}$ along the right edge of the roadway except at right curves, where the delineators were placed on the left edge of the roadway. Pattern 7 used crystal delineators at normal spacing along the right edge of the roadway. However, at right curves amber delineators were placed on the left edge of the roadway.) The amber delineators assist the driver in clearly defining the left edge of the roadway at right curves. He is not faced with the "clutter" situation that accompanies Patterns 3, 5, and 6. The clutter situation is caused by crystal delineators from the left edge interplaying visually with ones from the right edge as the driver proceeds through the curve. The resulting visual effect diminishes the value of the post delineators, because it takes the driver longer to perceive the intended information. The normal spacing between delineators on curves could also be increased. However, the revised spacing (two times the normal) used in this experiment does not seem to provide an adequate number of delineators to portray the needed information. Some intermediate spacing (perhaps $3\sqrt{R}$) should be used. These recommendations are personal preferences obtained by subjective evaluation.

In Phase II, raised pavement markers were studied as a substitute for a painted center line. Also, post delineators, placed according to Pattern 7 (outside of curve, amber delineators), were evaluated in conjunction with the RPM's and a new painted center line.

Changes in at least one study variable, lateral placement variance, provided a basis for conclusions and reinforced the researchers' subjective evaluation. Raised pavement markers show an advantage over a painted center line in that they cause drivers to move farther away from the center line and reduce variance in the travel path. This is true both with and without post delineators. Thus, the use of raised pavement markers on hazardous horizontal curves is recommended.

APPENDIX N

EVALUATION OF RAISED PAVEMENT MARKERS ON A RURAL CURVE *

PURPOSE OF STUDY

Past studies of raised pavement markers (RPM's) have generally been concentrated on lane lines and edge lines on median divided, multi-lane highways. The purpose of this study was to investigate the effect of RPM's on driver performance at horizontal curves on two-lane rural highways.

The motorist is normally provided with advance knowledge of coming curves through warning of curve and advisory speed signs. In addition, post delineators are sometimes used to outline curves in problem locations. The driver, however, requires a more positive guide to assist him in the actual tracking task while negotiating a curve. Freshly painted lane lines provide this "near delineation" in good weather, but they are not effective when faded or worn or during periods of inclement weather. For this reason, it was decided to initiate an experiment to see what effect RPM's (which are effective in inclement weather, as well as in good weather) would have on driver performance on two-lane rural roads.

SCOPE

A single horizontal curve was selected as a test site for this study to minimize problems associated with the temporary installation of RPM's and coordinating changes in edge striping for the various test configurations with the Pennsylvania Department of Transportation.

The selected location was studied under four delineation configurations:

1. Weathered center line and edge lines (Treatment 1).
2. Raised pavement markers installed as a double yellow center line (Treatment 2).
3. Freshly painted white edge lines with the RPM's (Treatment 3).
4. Freshly painted yellow center line and white edge lines—RPM's removed (Treatment 4).

Other variables considered were light conditions (day and night) and type of curve (right and left, looking in the direction of travel). All other factors were assumed to be constant so that any improvements could be attributed to the effects of the delineation treatment.

For each of the treatment conditions, spot speeds at the approach to and within the curve, and vehicle placement within the curve, were collected. A double row of low-intensity yellow markers (Fig. N-1) on 3-ft centers with 4 in. between the rows was used to simulate the center line; pairs were alternately reflectorized and non-reflectorized. Only the reflectorized markers were visible at night, but the relatively close spacing provided a clearly marked center line both day and night.

The chosen pattern is in general agreement with spacing recommendations of Louisiana (which uses this type of RPM) and the Institute of Traffic Engineers' unpublished report on RPM spacing.

TEST LOCATION

The following general criteria were considered in selecting a test site:

1. Traffic volumes should be adequate to obtain a sufficient sample during selected study hours.
2. Sufficient tangent section should be available on each end of the curve to permit measuring approach speeds before the vehicles were influenced by the curve.
3. Evidence of hazardous driving conditions should be present, such as a badly worn center line or a high-accident history.
4. No traffic control devices that could limit the free flow of vehicles should be present.
5. Grades through the study site should be sufficiently flat to eliminate their influence on speeds.

Based on these criteria a test site located on the edge of the campus of The Pennsylvania State University was selected.

The roadway is 24 ft wide, two-lane, two-way, and surfaced with a standard bituminous surface course. The horizontal curve has a 288-ft radius ($D_c = 20°$), a length of 440 ft, and is superelevated at 1 in. per foot of roadway. Passing is prohibited throughout the entire length of the curve and also on the approach sections of interest. Field observations revealed that free-moving vehicles on the left curve frequently cut across the center line. Accident records showed a high accident cluster on this curve. Intramural athletic fields located adjacent to both sides of the road could contribute to distracting drivers.

The only delineation devices present were curve-arrow signs, with advisory speeds, and a few post delineators on one approach tangent.

EXPERIMENTAL PROCEDURE

Radar meters were used to collect speed data, and electrically segmented placement tapes connected to a 20-pen recorder were employed to record vehicle lateral placement. The locations within the study site for each of these measurements are shown in Figure N-2.

Approach speeds were taken before the driver was influenced by the coming curve. Curve speeds were mea-

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sured near the apex of the curve; past studies had established that most drivers maintain a constant speed after entering a curve.

Points of maximum center line encroachments were selected by preliminary field observations and placement data were collected at these locations. The placement tapes were somewhat conspicuous to drivers during daylight hours, but there was no indication that drivers adjusted their lateral position on the roadway. The placement tapes did affect daytime speeds. However, this was of no consequence because daylight speeds and placements were not measured concurrently.

Approximately 100 observations were obtained at each data collection point for each treatment. In general, all data for a single treatment were collected within a single daytime and nighttime data collection period; in a few cases it was necessary to return to the field a second day (or night) to obtain the desired number of observations. Only free-moving vehicles not influenced by opposing traffic were included in the sample. It was believed that the speed and placement characteristics of vehicles free from the influence of other traffic would more clearly reflect the influence of the delineation treatment. The following guidelines were used in selecting vehicles:

1. Approach speeds—single vehicles, or the first vehicle in a platoon, were recorded if no previous vehicle still occupied the tangent section within a distance that could influence the speed. Opposing traffic was not considered critical unless it was within approximately 100 ft of the sector covered by the radar meter.

2. Curve speeds—Vehicles were recorded only if there were no opposing or leading vehicles within the confines of the curve. In the case of platooned vehicles, only the leading vehicle was recorded. During night conditions the required separation was increased to reduce the influence of oncoming headlights.

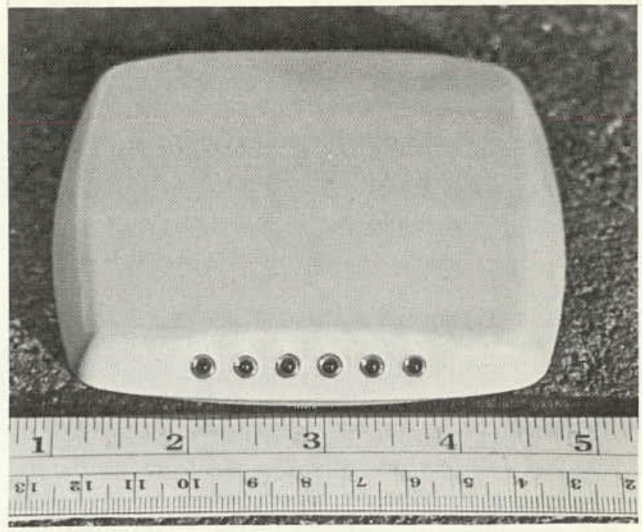

Figure N-1. Low-reflectivity marker—Safety Guide.

3. Placement—The criterion for selection was the same as for curve speeds. At night it was observed that following vehicles tended to "track" lead vehicles when taillights from a lead vehicle could be observed. The required separation between vehicles was increased to eliminate this effect.

4. Speed and placement data were collected for passenger cars only.

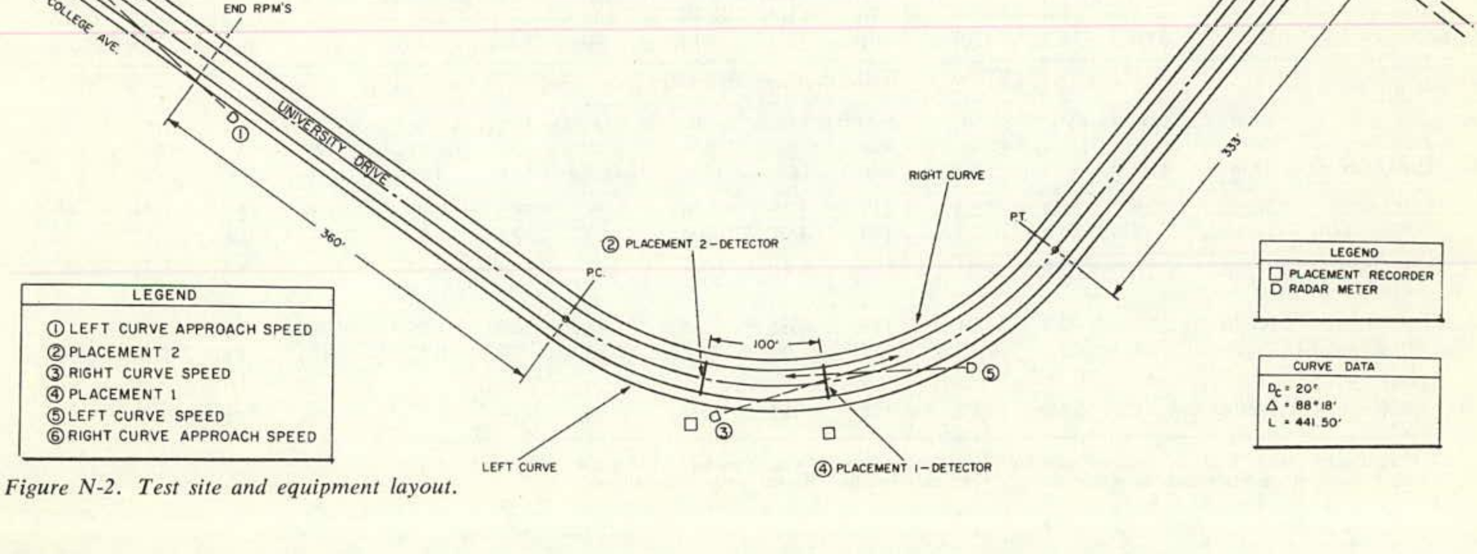

Figure N-2. Test site and equipment layout.

ANALYSIS OF DATA

The data collected during this study lend themselves to many possible combinations of comparisons. The end objective, however, was to provide information to determine the effectiveness of RPM's in improving driver performance on hazardous rural curves.

For data analysis, the test site was subdivided into four separate cells—(a) left curve night, (b) left curve day, (c) right curve night, (d) right curve day. Each of these cells had been subjected to the four delineation treatments: Treatment 1—weathered center line and edge lines; Treatment 2—RPM's; Treatment 3—RPM's and edge lines; Treatment 4—painted center line and edge lines. The first three treatments are shown in Figures N-3, N-4, and N-5. The fourth treatment was the standard paint pattern.

For each cell, the means and variances of speeds and lateral placements were compared across the four treatments for evidence of improved driver performance. An analysis of variance and Duncan's multiple range test were used to determine if the treatment mean values of speeds and lateral placement were significantly different. An *F*-test was used to detect any significant changes in the variances.

A combination of absolute changes in mean speeds and lateral placements, as well as reductions in their variability, were used for evaluating improvement in driver performance. In evaluating traffic behavior variables such as speed and placement, an improvement can be claimed if the variability is reduced by the introduction of the delineation treatment under study. A reduction in variability indicates that motorists are driving in a more uniform manner —i.e., trajectories are similar and there are fewer deviations from normal.

Statistical comparisons were not performed between cells because the tracking tasks and driver visual input requirements are different for night and day lighting conditions and right and left curves. Further, differences between day and night conditions contain an unaccounted-for bias resulting from normal day to night differences in speed and placement. However, general observations on relationships between cells are pointed out, where appropriate, in the discussion of results.

DISCUSSION OF RESULTS

Data Summary

The first phase of the data analysis involved reduction of field data for each of the 32 speed and 23 lateral placement sample distributions. Sample sizes, means, and standard deviations for all samples are summarized in Table N-1.

The second phase of the data analysis was to determine

TABLE N-1

STATISTICAL SUMMARY FOR VEHICLE SPOT SPEEDS AND VEHICLE PLACEMENTS

(*a*) VEHICLE SPOT SPEEDS

TEST LOCATION	LIGHT CONDITION	TREATMENT 1 [a] SAMPLE SIZE (NO.)	AVG. SPD. (MPH)	STD. DEV. (MPH)	TREATMENT 2 [b] SAMPLE SIZE (NO.)	AVG. SPD. (MPH)	STD. DEV. (MPH)	TREATMENT 3 [c] SAMPLE SIZE (NO.)	AVG. SPD. (MPH)	STD. DEV. (MPH)	TREATMENT 4 [d] SAMPLE SIZE (NO.)	AVG. SPD. (MPH)	STD. DEV. (MPH)
Left curve approach	Night	80	39.5	4.03	100	38.9	5.21	100	39.8	4.78	101	39.9	4.48
	Day	105	39.8	4.52	100	40.2	5.42	100	41.4	4.66	102	37.5	4.58
Left curve	Night	69	30.4	4.76	82	31.9	3.95	87	33.3	4.42	95	33.4	4.53
	Day	104	34.2	3.12	101	32.1	5.38	84	33.8	3.43	100	33.9	3.92
Right curve approach	Night	82	40.0	5.35	100	40.7	5.95	99	38.9	4.80	82	40.5	4.63
	Day	108	40.1	5.54	103	37.6	4.67	101	40.0	5.17	100	39.7	5.62
Right curve	Night	75	33.6	3.84	90	31.3	3.78	100	31.6	3.68	101	32.1	3.15
	Day	110	35.0	3.49	101	32.7	4.18	80	33.9	4.30	100	34.1	3.78

(*b*) VEHICLE PLACEMENTS

TEST LOCATION	LIGHT CONDITION	TREATMENT 1 SAMPLE SIZE (NO.)	AVG.[e] L.P. (FT)	STD. DEV. (FT)	TREATMENT 2 SAMPLE SIZE (NO.)	AVG.[e] L.P. (FT)	STD. DEV. (FT)	TREATMENT 3 SAMPLE SIZE (NO.)	AVG.[e] L.P. (FT)	SPD. DEV. (FT)	TREATMENT 4 SAMPLE SIZE (NO.)	AVG.[e] L.P. (FT)	STD. DEV. (FT)
Left curve, Placement 1	Night	129	2.58	1.53	111	3.28	1.14	89	3.21	0.98	105	2.32	1.11
	Day	85	2.19	1.67	103	4.01	1.03	93	3.68	0.91	98	1.66	1.11
Left curve, Placement 2	Night	97	2.31	1.83	128	3.41	0.99	101	3.31	0.90	100	2.31	1.24
Right curve, Placement 1	Night	129	4.39	1.21	112	4.62	1.24	95	4.51	1.03	100	4.06	1.27
	Day	88	4.31	1.40	117	5.02	0.97	115	3.73	0.87	85	4.42	1.14
Right curve, Placement 2	Night	81	3.66	1.27	118	4.14	1.42	—[f]	—[f]	—[f]	99	3.64	1.20

[a] Weathered paint lines. [b] Raised pavement markers. [c] RPM's and painted edge lines. [d] Painted center and edge lines. [e] Mean distance from vehicle's left wheels to center line. [f] No data obtained due to equipment failure.

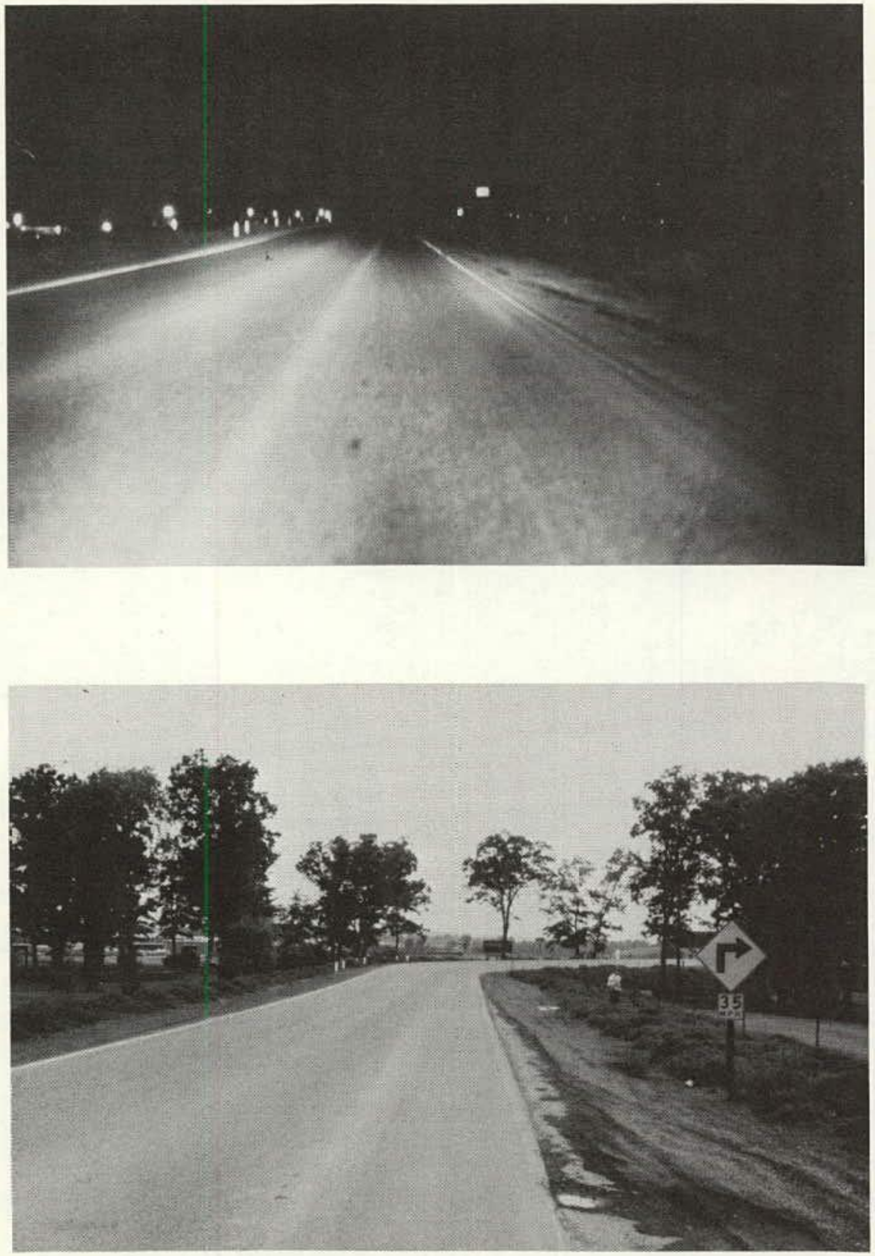

Figure N-3. Test site with weathered center line and edge lines: (upper) left curve at night; (lower) right curve by day.

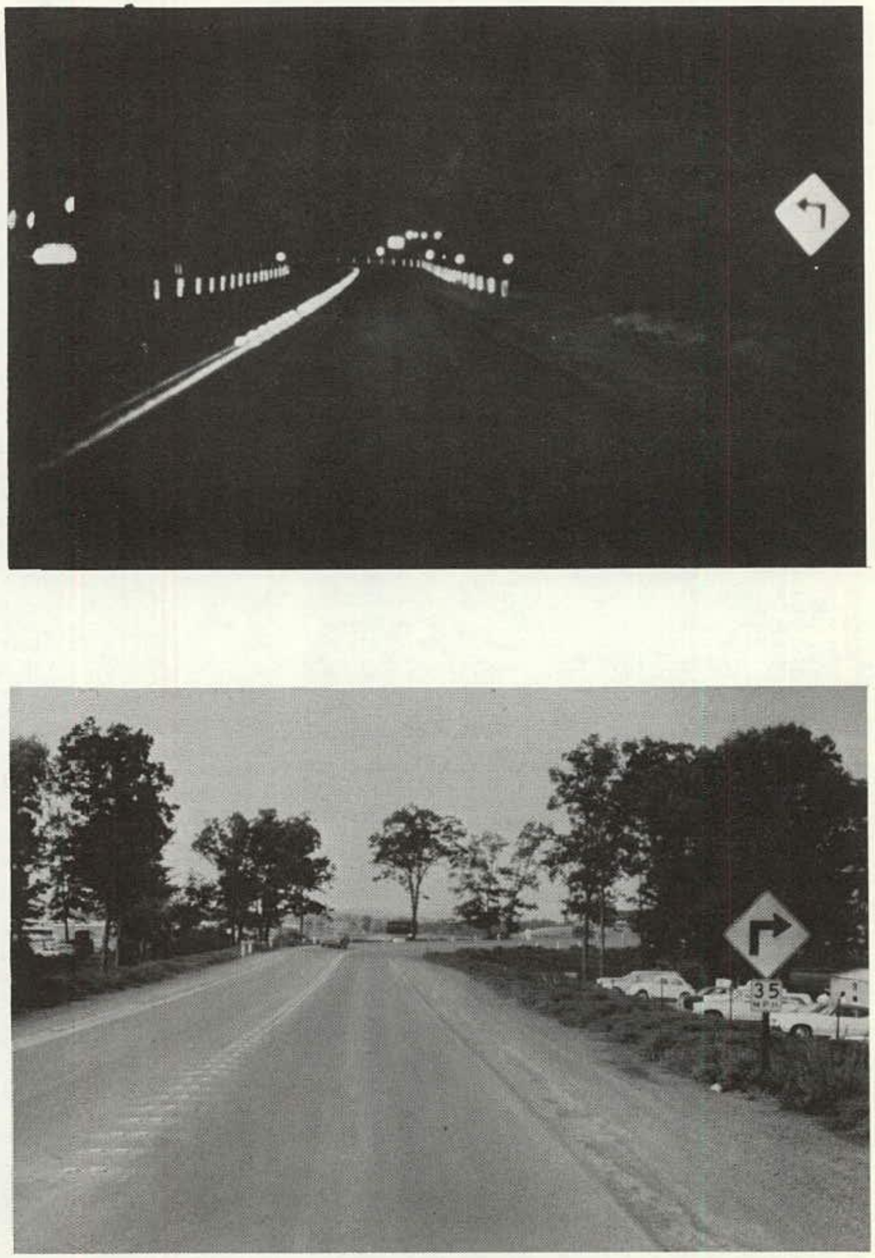

Figure N-4. Test site raised pavement markers: (upper) left curve at night; (lower) right curve by day.

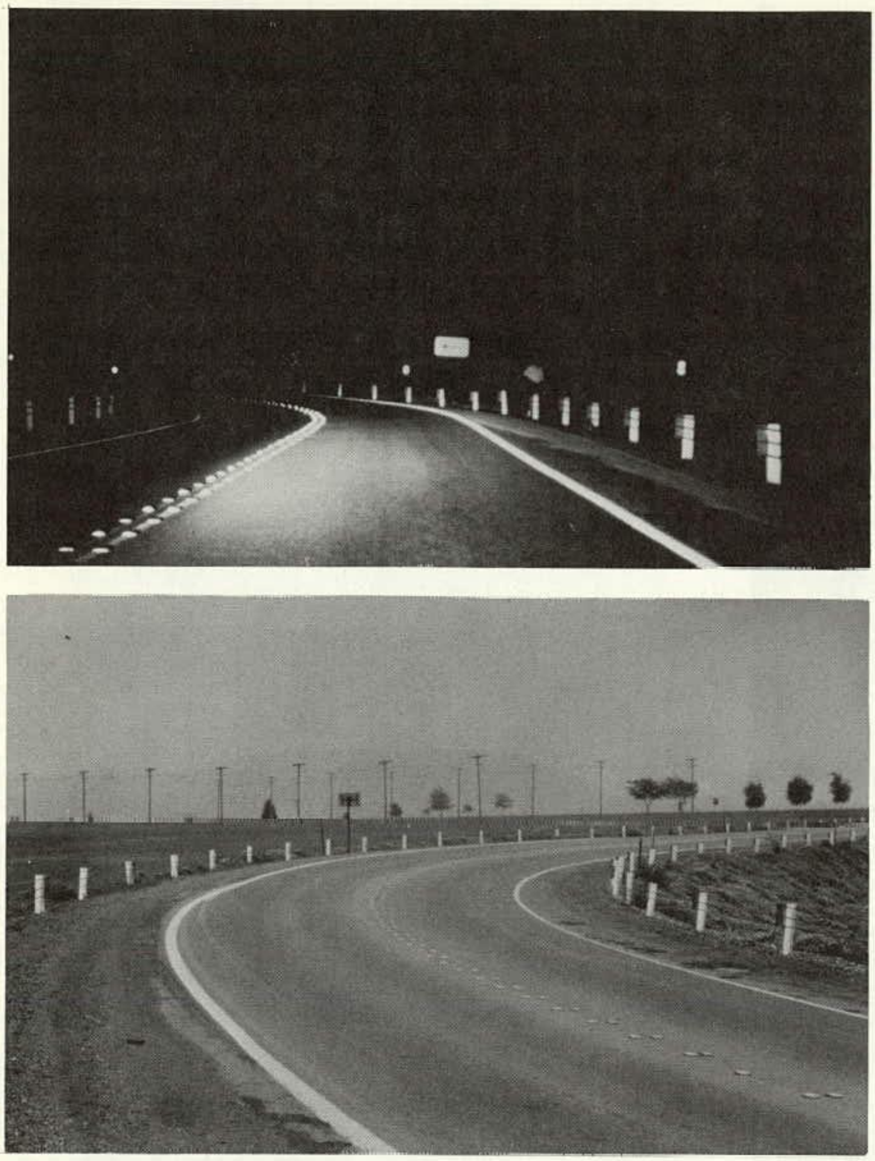

Figure N-5. Test site with raised pavement markers and edge lines: (upper) left curve at right; (lower) right curve by day.

if any of the speed and placement distributions differed among treatments. The means were compared using an analysis of variance test and Duncan's multiple range test; the variances were compared using an *F*-test.

Results of Spot Speed Comparisons

Mean Values

Table N-2 shows that significant changes in the mean for speeds taken at the approaches to the curves occurred in only a few instances. This was to be expected, because the delineation changes were made within the curve and should not measurably affect the approach speed. Several significant differences did appear in mean speeds within the curve. Comparisons among the four situations (i.e., left curve, day and night, and right curve, day and night) indicate that speeds for those treatments with RPM's were generally lower than for those without.

Variances

The majority of treatment comparisons of variability showed no significant difference. Those that did change did not display any apparent trend.

The foregoing results indicate that speeds were not materially affected by the delineation treatments used in this experiment.

Results of Lateral Placement Comparison

The results of the placement data analyses (Table N-3) are more conclusive than those for the speed data. The

TABLE N-2

COMPARISONS OF SPEEDS ON CURVE UNDER VARIOUS TREATMENTS

TEST LOCATION	LIGHT CONDITION	TREATMENT COMPARISON [a] a	b	LEFT CURVE SIGN. OF MEAN [b]	LEFT CURVE SIGN. OF VARIANCE [b]	RIGHT CURVE SIGN. OF MEAN [b]	RIGHT CURVE SIGN. OF VARIANCE [b]
Curve approach	Night	1	2	−NS	+ S	+NS	+NS
		1	3	+NS	+NS	−NS	−NS
		1	4	+NS	+NS	+NS	− S
		2	3	+NS	−NS	−NS	− S
		2	4	+NS	−NS	−NS	− S
		3	4	+NS	−NS	+NS	−NS
Curve	Night	1	2	+ S	−NS	− S	−NS
		1	3	+ S	−NS	− S	−NS
		1	4	+ S	−NS	− S	− S
		2	3	+ S	+NS	+NS	−NS
		2	4	+ S	+NS	+NS	− S
		3	4	+NS	+NS	+NS	−NS
Curve approach	Day	1	2	+NS	+ S	− S	− S
		1	3	+ S	+NS	−NS	−NS
		1	4	− S	+NS	−NS	+NS
		2	3	+NS	−NS	+ S	+NS
		2	4	− S	−NS	+ S	+NS
		3	4	− S	−NS	−NS	+NS
Curve	Day	1	2	− S	+ S	− S	+NS
		1	3	−NS	+NS	− S	+ S
		1	4	−NS	+ S	−NS	+NS
		2	3	+ S	− S	+ S	+NS
		2	4	+ S	− S	+ S	−NS
		3	4	+NS	+NS	+NS	−NS

[a] 1 = weathered center line and edge lines; 2 = raised pavement markers; 3 = raised pavement markers and edge lines; 4 = painted center line and edge lines.
[b] NS = not significant; S = significant; ± = increase or decrease in mean or variance (b compared to a); 0.05 level of significance was used.

TABLE N-3

COMPARISONS OF LATERAL PLACEMENTS ON CURVE UNDER VARIOUS TREATMENTS

TEST LOCATION	LIGHT CONDITION	TREATMENT COMPARISON [a] a	b	LEFT CURVE SIGN. OF MEAN [b]	LEFT CURVE SIGN. OF VARIANCE [b]	RIGHT CURVE SIGN. OF MEAN [b]	RIGHT CURVE SIGN. OF VARIANCE [b]
Placement 1	Night	1	2	+ S	− S	+NS	+NS
		1	3	+ S	− S	+NS	−NS
		1	4	−NS	− S	−NS	+NS
		2	3	−NS	−NS	−NS	− S
		2	4	− S	+NS	− S	+NS
		3	4	− S	−NS	− S	+ S
	Day	1	2	+ S	− S	+ S	− S
		1	3	+ S	− S	− S	− S
		1	4	− S	− S	+NS	− S
		2	3	− S	−NS	− S	−NS
		2	4	− S	+NS	− S	+NS
		3	4	− S	+ S	+ S	+ S
Placement 2	Night	1	2	+ S	− S	+ S	+NS
		1	3	+ S	− S	—	—
		1	4	−NS	− S	−NS	−NS
		2	3	−NS	−NS	—	—
		2	4	− S	+ S	− S	− S
		3	4	− S	+ S	—	—

[a] 1 = weathered center line and edge lines; 2 = raised pavement markers; 3 = raised pavement markers and edge lines; 4 = painted center line and edge lines.
[b] NS = not significant; S = significant; ± = increase or decrease in mean or variance (b compared to a); 0.05 level of significance was used.

TABLE N-4

SUMMARY OF CENTER LINE ENCROACHMENTS

TEST LOCATION [a]	LIGHT CONDITIONS	ENCROACHMENTS (NO.) FOR TREATMENT [b] 1	2	3	4
Placement 1	Night	5	0	0	1
Placement 2	Night	7	0	0	2
Placement 3	Day	8	0	0	1

[a] See Figure N-2.
[b] 1 = weathered center line and edge lines; 2 = raised pavement markers; 3 = raised pavement markers and edge lines; 4 = painted center line and edge lines.

data show that RPM's, RPM's with edge lines, or the freshly painted center line with edge lines were better than the weathered paint lines. On the left curve, every comparison of alternative treatments with the weathered paint lines showed a significant decrease in the variability of driver placement. This trend is also present for the right curve; however, a number of the differences were not statistically significant. The need for keeping pavement markings (either RPM's or painted lines) in good condition is apparent.

A comparison of Treatment 4 with Treatments 2 and 3 indicates that the mean distance from the center line is greater and the variability of vehicle placement is less when RPM's are used for the center line rather than painted lines. This trend is evident for both the right and the left curve, as well as the night and the day conditions.

Another measure of the relative effectiveness of the treatments is given in Table N-4, which gives the number of center line encroachments by vehicles traveling in both directions. No encroachments were noted when RPM's were present. Whether the visibility of the RPM's or their rumble effect contributed the most to this improvement is not known.

TABLE N-5

SUMMARY OF TREATMENT COMPARISONS

		STATISTICALLY SIGNIFICANT CHANGE [a]								
		LEFT CURVE					RIGHT CURVE			
		TANGENT		CURVE			TANGENT		CURVE	
					NIGHT					
VARIABLE	STATISTIC	DAY	NIGHT	DAY	1	2	DAY	NIGHT	DAY	NIGHT
(a) Is the freshly painted center line and edge line treatment better than the weathered center line and edge line treatment? [b]										
Speed	Reduced mean	Yes	—	—	No		—	—	—	Yes
	Red. variance	—	—	No	—		—	Yes	—	Yes
Lateral placment	Mean farther from center line			No	—	—			—	—
	Red. variance			Yes	Yes	Yes			Yes	—
Center line crossovers	Red. frequency			Yes	Yes	Yes				
(b) Is the RPM's and edge line treatment better than the freshly painted center line and edge line treament? [c]										
Speed	Reduced mean	No	—	—	—		—	—	—	—
	Red. variance	—	—	—	—		—	—	—	—
Lateral placement	Mean farther from center line			Yes	Yes	Yes			No	Yes
	Red. variance			Yes	—	Yes			Yes	Yes
Center line crossovers	Red. frequency			Yes	Yes	Yes				
(c) Is the RPM's and edge line treatment better than the RPM's only treatment? [d]										
Speed	Reduced mean	—	—	No	No		No	—	No	—
	Red. variance	—	—	Yes	—		—	Yes	—	—
Lateral placement	Mean farther from center line			No	—	—			No	—
	Red. variance			—	—	—			—	Yes
Center line crossovers	Red. frequency			—	—	—				

[a] Yes or No indicates a statistically significant change; —indicates no statistically significant change occurred; blank indicates no test. [b] Treatment 4 vs Treatment 1. [c] Treatment 3 vs Treatment 4. [d] Treatment 3 vs Treatment 2.

The data are presented in still another fashion, perhaps more directly useable. In Table N-5 questions are posed to determine which delineation treatment is "better." A treatment is considered "better" if it meets all or a majority of the following requirements:

1. The mean speed and variance is reduced.
2. The distance from the center line is increased and the placement variance is reduced.
3. The frequency of center line crossovers is reduced.

Table N-5a shows that in several categories, especially in reduced variance of placement, a statistically significant improvement is shown for freshly painted center lines and edge lines over weathered lines.

Table N-5b shows that the speeds (both mean and variance) are not noticeably affected by the treatments. However, in considering lateral placement and frequency of center line encroachments, RPM's and edge lines are better than the painted center line and edge line treatment.

Table N-5c does not appear to show that the two treatments (RPM's and edge line vs RPM's only) have different effects. Although the mean speeds were greater in four situations with the addition of edge lines, the variance of the speeds was reduced in two situations. There is no trend apparent as regards lateral placement or center line crossovers.

In summary, it appears that Treatments 2 (RPM's only) and 3 (RPM's and painted edge line) produced the most desirable traffic behavior. Both brought about a reduction in placement variability as well as a more central position in the traveled lane. Because both treatments incorporated RPM's, it can be theorized that the improvement is due to the presence of the raised pavement markers. Also, it should be recognized that only free-flowing vehicles in good weather were recorded. RPM's, with their reflective character and raised position on the roadway, should provide even better results in adverse weather.

CONCLUSIONS

The results of this experiment are summarized as follows:

1. Speeds of passenger vehicles were not practically affected by the four delineation treatments studied. Although the data are not conclusive, there was a tendency for speeds to be lower within the curve when raised pavement markers were present.

2. The analyses of the lateral placement data indicate that this variable is sensitive to the delineation treatments. As expected, it is evident that any delineation marking on the roadway (Treatments 2, 3, or 4) is better than no delineation marking.

3. Of the four treatments studied, Treatment 3 (RPM's and painted edge lines) produced the most desirable effect. It not only reduced the vehicular placement variability, but also caused the drivers to adopt a more central position in their lane. The next best treatment was RPM's only (Treatment 2). This treatment showed reduction in vehicular placement variability when compared to Treatments 1 and 4. Also, this treatment produced the greatest mean distance away from the center line for all situations.

The conclusions of this study are limited by the fact that only free-flowing cars in good weather were recorded. Because of their reflective character and raised position on the roadway surface, RPM's should prove to be even more favorable than paint lines under adverse weather conditions.

Other Considerations

Besides the previously mentioned analytical conclusions, other observations that should be noted include:

1. Several favorable letters were received from motorists regarding the raised pavement markers. Generally their comments were that they felt more at ease driving through the curve. No one responded negatively to the rumble effect produced by the markers.

2. The visibility of the markers at night was excellent, especially during rain. The pattern employed was adequate in simulating a double yellow line, both day and night. It was noted, however, that several of the markers were blackened on the top by tire marks.

3. Although an accurate and meaningful cost comparison cannot be made from this one experiment, it is interesting to note the cost differences of raised pavement markers and paint lines. The rough calculation presented in the following indicates that raised pavement markers, placed as they were in this study, are more expensive than standard paint lines.

Raised pavement markers:

380 reflective markers @ $0.67	=	$ 254
380 non-reflective markers @ $0.40	=	152
Devices	=	406
Labor (Estimated)	=	812
Total	=	$1,218
Cost per foot of double yellow line	=	$1.07
Useful life	=	3 yr

Painting:

Painted lines, avg. cost (per foot)	=	$0.022
× double line (per foot)	=	$0.044
× 2 painting cycles per year (per foot)	=	$0.088

Summary:

Average cost of RPM's per year =	$1.07/3 = $0.36
Average cost of paint per year =	$0.09

The high cost for the raised pavement markers could be reduced by using a greater spacing. Due to the higher costs, it would seem advisable to install RPM's initially only on curves that have a high accident history. If accidents are reduced significantly at these trial installations, serious consideration should be given to wide-scale installation of RPM's at horizontal curves on two-lane highways.

4. Because the addition of edge lines to the RPM center line treatment did not materially improve traffic performance, the use of edge lines at isolated treatment locations should be dependent on whether or not they are used on the adjacent sections of highway.

APPENDIX O

CENTER LINE MARKING PATTERNS *

The importance of a painted, reflectorized center line cannot be overemphasized. The *Manual on Uniform Traffic Control Devices* states that on all major rural highways and on many urban streets and less important rural highways, center lines are necessary and should be provided. The center line serves as a warning and control device and conveys information to the driver without diverting his attention from the roadway.

This study was concerned only with paint patterns that permit passing maneuvers; that is, dashed lines on rural roads. The recommended procedure for painting center lines for a passing condition is to use line segments having a 3:5 ratio of stripe to gap; more specifically, painted segments 15 ft in length with 25-ft gaps. This pattern produces a 40-ft module of paint stripe plus gap length.

This recommended procedure does not seem founded on any scientific principle and the literature offers no explanation of its origin. Therefore, it seems logical to study other ratios and patterns that would offer adequate delineation, convey the same meaning, and also reduce paint costs.

PURPOSE OF STUDY

It was the intent of this study to determine the effects of an alternate, more economical passing paint pattern on the speed and lateral placement of vehicles. Also studied was the effect of edge lines on the various treatments tested. Due to limitations of time and equipment, only one test pattern was studied.

It was hypothesized that there would be no significant difference, statistically or practically, between the test pattern and the standard pattern in terms of vehicle speed and lateral placement. Subjective opinions were also solicited from associates who drove over the test section. Although other variables such as driver comfort, overtaking and passing maneuvers, and accident records may have been considered in this study, it was believed that time and scope allowed for the inclusion of speed and lateral placement measurements only.

METHOD OF STUDY

Spot speeds were measured by means of a radar unit. Lateral placement data were collected by use of a lateral placement tape and a 20-pen recorder.

Data were collected for five different treatments during the day and at night. The mean, standard deviation, variance, and standard error of the mean were calculated for each set of data. Statistical analyses were performed on the data to determine if significant differences between treatments did exist.

SELECTION OF SITE

In choosing a suitable location for conducting this study, several criteria had to be met, as follows:

1. The site had to be located on a two-lane rural highway not less than 20 ft and not more than 24 ft wide. It could not have any observable center joint that could be used for guidance in place of a painted center line.
2. The section of roadway chosen had to contain a tangent section at least 2,000 ft in length with legal passing permitted throughout. It also had to contain a crest vertical curve that offered a reduction in sight distance while still allowing passing maneuvers.
3. The site had to be void of a painted center line and edge lines or the lines had to be so worn away that they could be considered nonexistent.
4. The route containing the test section had to have sufficient traffic to allow the required sample to be collected in a reasonable amount of time.

It was mandatory that several of these criteria be met if any interpretation was to be made of the data collected. Twenty feet was set as the lower limit for pavement width because this is the narrowest two-way, two-lane highway that is painted with edge lines in Pennsylvania.

A visible center joint has been shown to have a guiding influence on vehicles even when a painted center stripe is absent. Lack of any such joint would allow the driver to receive guidance information only from the center line pattern that was placed on the roadway. If all other conditions were kept constant and only the center line was varied, any significant differences in driver behavior could reasonably be attributed to the difference in center line.

It was believed that the driver should be allowed sufficient time to adjust to the test pattern before his speed and lateral placement were recorded. For this reason, a tangent section of at least 2,000 ft was required. To determine driver behavior when sight distance is less than unlimited, a crest vertical curve that was severe enough to limit the driver's visibility to no more than 9 or 10 modules, but not severe enough to prohibit passing, was required.

The site that most nearly fulfilled the foregoing requirements was located on Pennsylvania Route 26 in Centre County, approximately 2 miles west of the intersection of Routes 322 and 26.

The roadway throughout the test section is 20 ft wide, two-lane, two-way, with compacted earth shoulders. It is surfaced with a bituminous concrete surface course. Passing is permitted throughout the length of the section; the center line, which is badly worn and in many places nonexistent, is the standard 4-in. white reflectorized paint pattern of 15-ft stripe and 25-ft gap. A 4-in. edge line is

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present along both edges of the roadway, but it is also badly worn and not very noticeable. The horizontal and vertical alignments of the test section are shown in Figure O-1.

SELECTION OF TEST PATTERN

The basic objective of this study was to determine if a new passing paint pattern could be introduced that would require less paint per foot of roadway than the standard pattern, while relaying to the driver sufficient information to allow him to safely and comfortably negotiate the highway.

There are, of course, many patterns that could be tested to serve this purpose, one of which would offer the maximum degree of delineation at the minimum cost. At best, the determination of this pattern could be a trial and error procedure. It is even doubtful that the degree of delineation could be measured quantitatively in order to determine when this balance point is reached.

This raises the problem of measurement. How does one determine the effectiveness of any new pattern he may care to test? Inasmuch as the standard pattern (15-ft line and 25-ft gap) is so widely used and accepted, the most obvious method would be to measure driver reaction to the test pattern and compare this with driver reaction to the widely accepted standard pattern.

"Driver reaction" as used here can consist of many measureable quantities. Two of the most common measures of this type are speed and lateral placement. Their widespread use is due to their proven worth as accurate measures of driver performance, as well as the fact that they are easy and practical to collect.

The hypothesis of "no difference" assumes that the test pattern chosen is not so radically different from the standard pattern that it relays an entirely different type of information to the driver, but rather that it is similar enough to relay approximately the same information in a more economical manner.

The test pattern chosen for use was determined in a separate experiment. Several drivers traveled over a section of roadway containing four different patterns, as follows:

1. 5-ft line, 35-ft spacing = 40-ft module.
2. 10-ft line, 30-ft spacing = 40-ft module.
3. 3-ft line, 37-ft spacing = 40-ft module.
4. 3-ft line, 17-ft spacing = 20-ft module.

The drivers were then interviewed concerning their reactions to each of the patterns. The interviews were conducted by two psychologists well versed in highway and traffic engineering and were aimed at determining the answers to the following questions:

1. What *type* of information did the pattern relay to the driver?
2. How *much* information did the pattern relay to the driver?
3. Did the pattern divert the driver's attention to any great degree?
4. Did the driver feel that the pattern adversely affected his performance?

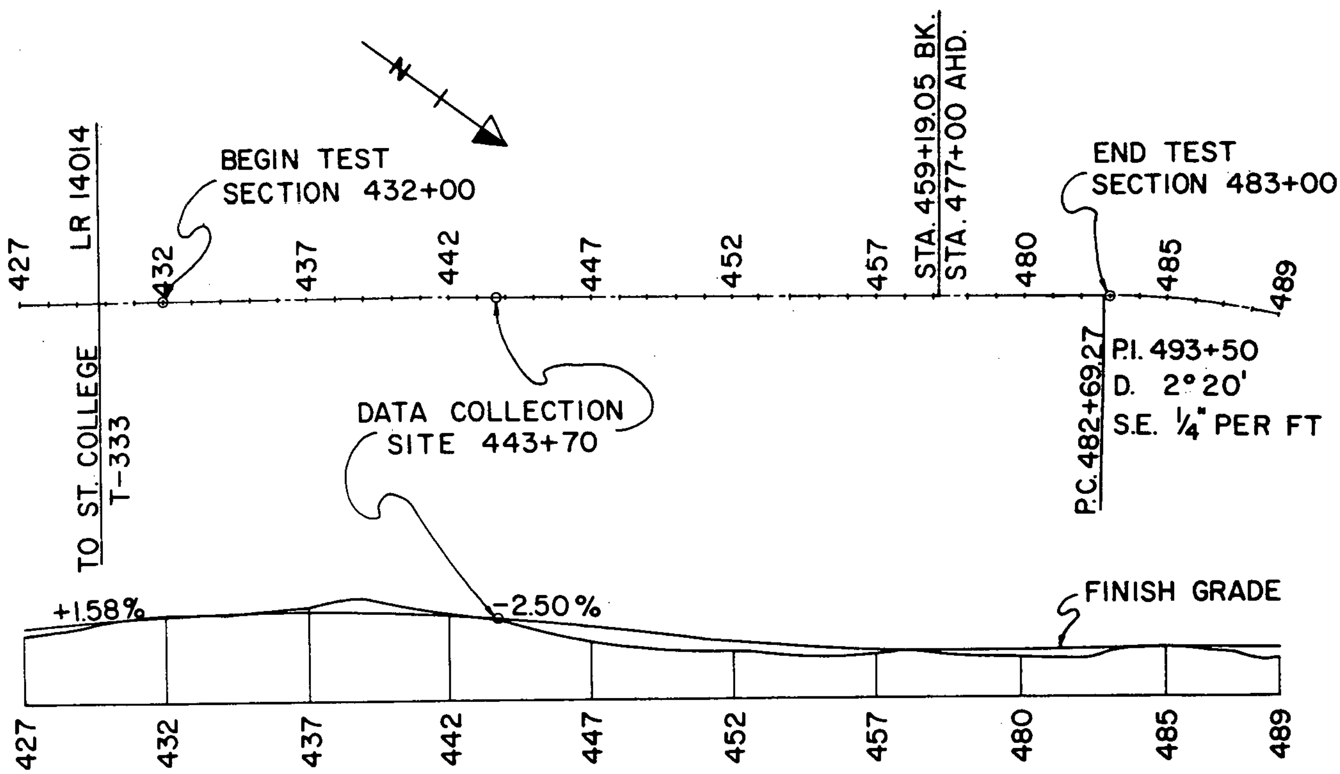

Figure O-1. Test section and data collection site.

5. Did the driver prefer the test pattern or the standard pattern?

If it is assumed that the major purposes of a center line skip pattern are to inform the driver that he can legally perform a passing maneuver and also to aid him in determining the proper placement of his vehicle on the traveled portion of the roadway, then, based on the results of the interviews, any one of the four patterns could have been chosen for future study. In every case, the drivers believed that they were being supplied with enough information to operate their vehicles confidently.

Because the main concern was to effect an over-all reduction in paint costs, the pattern consisting of a 10-ft line and a 30-ft spacing was eliminated because it offered an over-all reduction of only 33 percent in paint costs. The pattern consisting of a 3-ft line and a 37-ft spacing offers the largest reduction (80 percent), but it was believed that a reduction of this magnitude may have resulted in stronger driver opposition had the experiment been carried out on a larger scale. The two remaining patterns, 5-ft line and 35-ft spacing and 3-ft line and 17-ft spacing, offered approximately the same cost reductions (67 percent and 60 percent, respectively). The 5-ft line and 35-ft spacing was finally chosen because it was much easier to coordinate its use with the standard pattern in the actual study.

INSTALLATION OF CENTER LINE

The test section in its original state nearly satisfied the requirements of a "null" condition; however, the old edge line and center line were evident in several places. A light coat of black asphaltic roof paint was used to cover these lines. The paint was thinned considerably with a thinning agent so that when applied it did not result in a glossy shine (which would have been as undesirable as the old paint lines themselves). Instead, it merely reduced the effectiveness of the glass beads and made the old lines blend into the rest of the roadway.

The center line markings used in this study were not paint lines, but were a temporary roll-on 4-in. tape that is designed exclusively for this purpose and contains reflectorized glass beads on its surface. At night under artificial illumination it was judged as bright as, or brighter than, a newly painted line, with drop-on beads.

Soon after the data were collected under the null condition, the tape was laid down in 5-ft strips with 35-ft spacing. Traffic was given a three-day acclimation period before speed and placement studies were made again. The third condition was achieved by adding 10-ft strips of tape to the 5-ft strips already in place. Because the pattern in place was the standard pattern, no acclimation period was allowed and data were collected the same day.

The Pennsylvania Department of Transportation painted a 4-in. line along both edges of the test section and condition No. 4 was met. Data were again collected with no consideration given to acclimating the driver.

Condition No. 5 was easily achieved by removing the 10-ft strips that had been placed to achieve condition No. 3. A four-day period was allowed for drivers to adjust to the new condition before data were collected.

DATA COLLECTION

The objective of the data collection phase of the study was to record the speed and lateral placement of free-flowing vehicles at the selected location during both daylight and darkness for the five study treatments of:

1. No center line, no edge lines (null condition).
2. Test pattern with no edge lines.
3. Standard pattern with no edge lines.
4. Standard pattern with edge lines.
5. Test pattern with edge lines.

The patterns are shown in Figures O-2, O-3, O-4, and O-5.

An attempt was made to collect a sample of at least 100 observations of vehicle speed and lateral placement per treatment at each location. It was felt that a sample size of this magnitude would be adequate for this type of study. To be sure, each sample size was checked as to its adequacy by use of the formula:

$$N = \left(\frac{K\sigma}{A}\right)^2 \tag{O-1}$$

in which

N = required sample size;
K = a constant depending on the desired level of service;
σ = standard deviation, as calculated from the collected data; and
A = allowable error, in mph in speed studies and in feet in lateral placement studies.

Inasmuch as the standard deviations of the collected data proved to be small (less than 1.10 for placement data and less than 10.3 for speed data), the sample size proved to be adequate in every case.

Only those vehicles that were considered to be free-flowing were included in each sample. Free-flowing vehicles, for the purpose of this study, were considered to be those vehicles that arrived at least 6 sec after the immediately preceding vehicles traveling in the same direction; and at least 6 sec after and 10 sec prior to passage of any vehicles traveling in the opposite direction. Use of the free-flowing concept was aimed at reducing or eliminating the effect of opposing and heading traffic on speed and lateral placement. Vehicles traveling in the same direction tend to follow the vehicle directly ahead of them in terms of their placement within the travel lane and also to match the speed of the lead vehicle. Although opposing traffic may not cause a decrease in vehicle speed, it was believed that it may have caused a shift in lateral placement away from the center of the roadway.

For the day condition, speeds and lateral placement were taken at different times. Although nighttime speeds were taken when the placement tape was down, the tape's black color and low reflective finish made it invisible until after the vehicle's speed had been recorded.

Figure O-2. Standard pattern (15-ft stripe, 25-ft gap) without edge lines; day view.

Figure O-3. Test pattern (5-ft stripe, 35-ft gap) without edge lines; day view.

Figure O-4. Test pattern (5-ft stripe, 35-ft gap) with edge lines; night view.

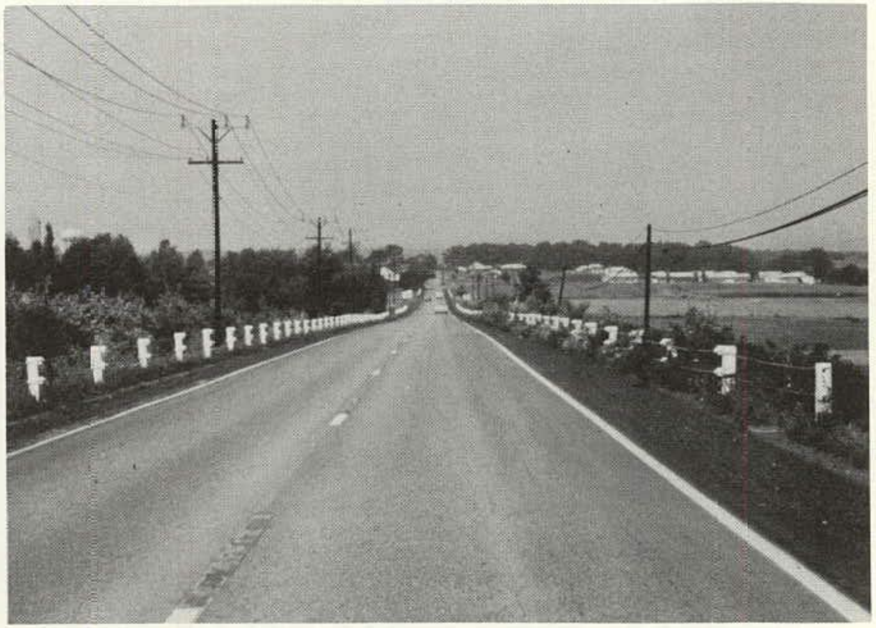

Figure O-5. Test pattern (5-ft stripe, 35-ft gap) with edge lines; day view.

ANALYSIS OF DATA

The speed and lateral placement summary data are presented in Tables O-1 and O-2. From the raw data, averages, standard deviations, variances, and standard errors of the mean were calculated.

To prove or disprove the original hypothesis, a statistical method of comparing "driver reaction" to the different center line treatments had to be chosen.

The *F*-test was considered appropriate in testing the validity of the assumption of identical standard deviations or homogeneity of the two sample variances. The *F*-test is performed as follows:

$$F = S_x^2/S_y^2 \tag{O-2}$$

where S^2 is the standard deviation squared (or variance) of each sample. In testing for the homogeneity of two variances the larger variance is always divided by the smaller variance, producing an *F*-value greater than 1. If the calculated *F*-value is greater than the tabulated *F*-value, the variances and standard deviations of the two samples are not homogeneous and are statistically different (at some given level of significance). A more thorough explanation may be found in any introductory statistics textbook.

A *t*-test was used to determine if differences in the mean values of speed and lateral placement were statistically significant. It is assumed that significant differences between means are attributable to the various center line or edge line treatments, because it is also assumed that all drivers are from the same population and, therefore, the difference between sample means is zero.

METHOD OF COMPARISON

The substantial volume of data collected during this study, coupled with the various combinations of conditions under which collections were made (limited sight distance, unlimited sight distance, treatments of center lines and edge lines, day and night), would permit many possible combinations for comparison.

Some combinations of treatments can be compared, but the results would be meaningless because the choice of using one in place of the other would probably never occur. For example, a traffic engineer may hypothetically decide to use either a 5-ft center stripe with edge lines or a 15-ft center stripe with edge lines, but it is doubtful that he would make his choice between the long line and the short line and consider the use of an edge line in one case and not in the other.

Comparing treatments that vary in the type of center line, as well as in the existence of an edge line, is also meaningless, insofar as any differences that arise cannot be attributed to either variable alone but must be attributed to the combined effort of both. Care was taken, therefore, to assure that only reasonable combinations of data were compared.

Conditions

Each condition, daylight or night, limited sight distance or unlimited sight distance, was analyzed separately. No attempt was made to compare the results of the same treatment under different conditions. For example, the test pattern (2) was compared with the standard pattern (3) for daylight conditions and limited sight distance. A comparison was also made between the test pattern (2) and the standard pattern (3) for night conditions and limited sight distance. No analyses were made on the test pattern (2) and standard pattern (3) to indicate the effects of day vs night conditions.

Primary Comparisons

A study of the various combinations of data, within a specific set of conditions, produced logical relationships for comparison. For example, the comparison of speeds and lateral placements when the center line pattern is changed from the standard pattern to the experimental pattern is of primary importance.

Because the standard and experimental patterns were studied both with and without edge lines, there are actually two primary comparisons (2-3 and 4-5). Conclusions drawn from these comparisons are the major purpose of this study and are, therefore, referred to as primary.

Secondary Comparisons

Due to the procedure in which the specific center line and edge line treatments were applied, other relationships became obvious. These relationships were considered of secondary importance to the over-all intent of this study, but were still considered of sufficient importance to include.

These relationships are:

1. The effect of a center line on the speeds and lateral placements of vehicles (1-2 and 1-3). These comparisons would also indirectly compare the test and standard center line patterns.
2. The effect of edge lines on speed and lateral placement (2-5).

RESULTS

Speed Trends

To discern any trends or patterns in the mean speed and variance data in Tables O-1 and O-2, Table O-3 was constructed. An increase in mean speed or variance is designated by a plus (+), whereas a decrease is shown by a minus (−) sign.

Table O-3 reveals the following:

1. The test pattern resulted in greater speed variability, especially at night, and an increase in mean speed, again at night, over the standard pattern; both patterns without edge lines.
2. The standard pattern with edge lines produced an increase in variability during the day over the test pattern with edge lines.
3. The mean speeds were generally higher for the null treatment, no center line or edge lines, than for the test pattern with no edge lines. This was particularly true at night.
4. The variability of the null treatment increased when compared to the standard pattern with no edge lines. The

TABLE O-1

VEHICLE SPOT SPEEDS

TREATMENT				UNLIMITED SIGHT DISTANCE								LIMITED SIGHT DISTANCE							
	CENTER LINE (FT)			DAY				NIGHT				DAY				NIGHT			
NO.	STRIPE	GAP	EDGE LINE	SAMPLE SIZE (NO.)	AVG. SPEED (MPH)	STD. DEV. (MPH)	S.E.M.[a] (MPH)	SAMPLE SIZE (NO.)	AVG. SPEED (MPH)	STD. DEV. (MPH)	S.E.M.[a] (MPH)	SAMPLE SIZE (NO.)	AVG. SPEED (MPH)	STD. DEV. (MPH)	S.E.M.[a] (MPH)	SAMPLE SIZE (NO.)	AVG. SPEED (MPH)	STD. DEV. (MPH)	S.E.M.[a] (MPH)
1.	Null; none		No	100	50.9	8.72	0.87	100	51.0	9.75	0.98	100	48.0	6.57	0.66	100	50.3	6.89	0.69
2.	5	35	No	100	50.5	7.16	0.72	100	50.5	10.23	1.02	100	50.1	6.94	0.69	100	48.2	6.84	0.68
3.	15	25	No	100	50.6	6.70	0.67	100	48.9	9.37	0.94	100	47.5	7.27	0.73	100	45.3	6.30	0.63
4.	15	25	Yes	100	51.9	8.11	0.81	100	50.7	7.19	0.72	100	47.5	7.17	0.72	100	48.7	7.24	0.72
5.	5	35	Yes	100	48.9	7.20	0.72	100	53.2	8.05	0.81	100	47.8	6.69	0.67	100	48.4	6.72	0.67

[a] Standard error of the mean.

TABLE O-2

VEHICLE LATERAL PLACEMENT

TREATMENT				UNLIMITED SIGHT DISTANCE								LIMITED SIGHT DISTANCE							
	CENTER LINE (FT)			DAY				NIGHT				DAY				NIGHT			
NO.	STRIPE	GAP	EDGE LINE	SAMPLE SIZE (NO.)	AVG. L.P. (FT)	STD. DEV. (FT)	S.E.M.[a] (FT)	SAMPLE SIZE (NO.)	AVG. L.P. (FT)	STD. DEV. (FT)	S.E.M.[a] (FT)	SAMPLE SIZE (NO.)	AVG. L.P. (FT)	STD. DEV. (FT)	S.E.M.[a] (FT)	SAMPLE SIZE (NO.)	AVG. L.P. (FT)	STD. DEV. (FT)	S.E.M.[a] (FT)
1.	Null; none		No	103	2.86	0.97	0.096	103	2.68	0.97	0.096	121	2.80	0.85	0.078	106	2.16	0.89	0.086
2.	5	35	No	94	2.98	0.93	0.096	81	3.28	0.84	0.093	99	2.58	1.01	0.101	135	2.30	1.09	0.090
3.	15	25	No	103	2.79	0.90	0.089	106	3.10	1.02	0.099	105	2.55	0.90	0.088	108	2.35	1.11	0.107
4.	15	25	Yes	103	2.71	0.81	0.082	98	2.92	0.96	0.097	99	2.52	0.86	0.087	113	2.37	1.00	0.094
5.	5	35	Yes	100	2.24	0.84	0.084	103	2.68	0.88	0.087	102	2.73	0.91	0.090	100	2.44	1.01	0.101

[a] Standard error of the mean.

mean speed of the null treatment over the standard pattern without edge lines increased for all conditions. This result is similar to observation 3.

5. An increase in variability is noted for the test pattern without edge lines over the test pattern with edge lines. Mean speeds are greater during the day and less at night when edge lines are not in use.

These observations indicate that edge lines have an effect on vehicle speed. With edge lines speed variability is reduced as more information is relayed to the driver. Without edge lines, average speeds are lower at night. This may be attributable to the smaller amount of information given to the driver.

Trends in Vehicle Lateral Placement

Table O-4 describes trends in the variability and average placement values by indicating the direction of change of those values for all conditions studied. A table of this type can be valuable in discerning patterns of practical significance that may not appear as statistically significant. The following observations can be made from a study of the table:

1. There are no patterns that can be classified as definite trends in regard to either the variability or the average placement values.
2. During the day the test patterns (with and without edge lines) seem to have greater variability and higher average placement values than the standard pattern.
3. In general, when treatments 2 and 3 are compared to treatment 1, they are found to be more variable and to have a higher average placement value.
4. The comparison of treatments 2 and 5, which introduces the effect of edge lines, shows that the variability of placement values is usually greater when edge lines are not present. (Also supported by other studies in this project.) This can be explained by the fact that a center line coupled with an edge line offers the driver a more defined path to travel and, therefore, less variability.

TABLE O-3

SPOT SPEED RESULTS, GENERAL TRENDS

	COMPARISON [a] OF TREATMENTS [b] FOR									
	VARIABILITY					MEAN SPEED				
CONDITIONS	2–3	4–5	1–2	1–3	2–5	2–3	4–5	1–2	1–3	2–5
Unlimited sight distance:										
Day	+	+	+	+	−	−	+	+	+	+
Night	+	−	−	+	+	+	−	+	+	−
Limited sight distance:										
Day	−	+	−	−	+	+	−	−	+	+
Night	+	+	+	+	+	+	+	+	+	−

[a] + = increase; − = decrease. [b] For treatment descriptions see Table O-1 or Table O-2.

TABLE O-4

LATERAL PLACEMENT RESULTS, GENERAL TRENDS

	COMPARISON [a] OF TREATMENTS [b] FOR									
	VARIABILITY					MEAN PLACEMENT				
CONDITIONS	2–3	4–5	1–2	1–3	2–5	2–3	4–5	1–2	1–3	2–5
Unlimited sight distance:										
Day	+	−	+	+	+	+	+	−	+	+
Night	−	+	+	−	−	+	+	−	−	+
Limited sight distance:										
Day	+	−	−	−	+	+	−	+	+	−
Night	−	−	−	−	+	−	−	−	−	−

[a] + = increase; − = decrease. [b] For treatment descriptions see Table O-1 or Table O-2.

Summary of Speed Comparisons

Tables O-5 and O-6 give the results of the mean speed and variability comparisons between treatments.

Unlimited Sight Distance, Day

The only significant difference in mean speeds under the condition of unlimited sight distance by day is between treatments 4 and 5. The standard pattern with edge lines had higher speeds than the test pattern with edge lines.

In terms of variability, a significant difference was recorded for treatment 1 (null condition) over treatment 3 (standard pattern without edge lines).

Unlimited Sight Distance, Night

Two statistically significant differences in mean speeds occurred under the condition of unlimited sight distance at night:

1. Speeds for treatment 5 (test pattern with edge lines) were greater than for treatment 4 (standard pattern with edge lines). This finding is opposite the results of the day analysis.
2. The test pattern with edge lines (treatment 5) produced higher speeds than the test pattern without edge lines (treatment 2). It is believed that this increase in speed is due to the presence of edge lines and that, because of the additional information relayed to the driver, vehicles were driven faster.

TABLE O-5

AVERAGE SPEED COMPARISONS

CONDITIONS	TREATMENT[a] COMPARISON a	b	DIFF. IN MEAN[b] SPEED (MPH)	t-VALUE	STATISTICAL SIGNIFICANCE[c]
Unlim. sight dist.:					
Day	2	3	−0.14	0.143	N.S.
	4	5	+3.00	2.851	0.01
	1	2	+0.41	0.363	N.S.
	1	3	+0.27	0.246	N.S.
	2	5	+1.65	1.625	N.S.
Night	2	3	+1.59	1.146	N.S.
	4	5	−2.42	2.243	0.05
	1	2	+0.59	0.418	N.S.
	1	3	+2.18	1.612	N.S.
	2	5	−2.70	2.074	0.05
Limited sight dist.:					
Day	2	3	+2.59	2.585	0.01
	4	5	−0.35	0.357	N.S.
	1	2	−2.09	2.188	0.05
	1	3	+0.50	0.511	N.S.
	2	5	+2.29	2.376	0.02
Night	2	3	+2.90	3.119	0.01
	4	5	+0.30	0.304	N.S.
	1	2	+2.09	2.152	0.05
	1	3	+4.99	5.366	0.001
	2	5	−0.18	0.188	N.S.

[a] For treatment descriptions see Table O-1 or Table O-2.
[b] $\bar{X}_a - \bar{X}_b$. [c] N.S. = not significant.

TABLE O-6

SPEED VARIABILITY COMPARISONS

CONDITIONS	TREATMENT[a] COMPARISION a	b	VARIANCE S_a^2	S_b^2	F-VALUE[b]	STATISTICAL SIGNIFICANCE[c]
Unlim. sight dist.:						
Day	2	3	51.2626	44.9194	1.1412	+N.S.
	4	5	65.8055	51.8257	1.2697	+N.S.
	1	2	75.9817	51.2626	1.4822	+N.S.
	1	3	75.9817	44.9194	1.6915	+0.02
	2	5	51.2626	51.8257	1.0109	−N.S.
Night	2	3	104.7146	87.8589	1.1918	+N.S.
	4	5	51.6536	64.7954	1.2544	−N.S.
	1	2	94.9882	104.7146	1.1024	−N.S.
	1	3	94.9882	87.8589	1.0811	+N.S.
	2	5	104.7146	64.7954	1.6160	+0.05
Limited sight dist.:						
Day	2	3	48.1546	52.7963	1.0963	−N.S.
	4	5	51.4241	44.7014	1.1503	+N.S.
	1	2	43.1094	48.1546	1.1170	−N.S.
	1	3	43.1094	52.7963	1.2247	−N.S.
	2	5	48.1546	44.7014	1.0773	+N.S.
Night	2	3	46.7938	39.6706	1.1796	+N.S.
	4	5	52.4180	45.2100	1.1594	+N.S.
	1	2	47.5050	46.7938	1.0152	+N.S.
	1	3	47.5050	39.6706	1.1975	+N.S.
	2	5	46.7938	45.2100	1.0350	+N.S.

[a] For treatment descriptions see Table O-1 or Table O-2. [b] Larger variance divided by smaller variance.
[c] N.S. = not significant.

The only significant difference noted in variability was between treatment 2 (test pattern without edge lines) and treatment 5 (test pattern with edge line). Variability is greater for treatment 2.

Limited Sight Distance, Day

Three significant changes in mean speeds occurred under the condition of limited sight distance by day:

1. Speeds for the test pattern without edge lines were greater than the standard pattern without edge line. For unlimited sight distance, the result was the opposite.
2. The test pattern without edge lines produced higher speeds than the null treatment. This is an expected result because with limited sight distance a center line stripe gives information and guidance to the driver.
3. Speeds for treatment 2 (test pattern without edge lines) were higher than for the test pattern with edge lines. For unlimited sight distance, the result was the opposite.

No significant variability was noted in speeds for this condition.

Limited Sight Distance, Night

Three significant differences in mean speeds resulted under the condition of limited sight distance at night:

1. The mean speed of treatment 2 (test pattern without edge line) was greater than the mean speed of treatment 3 (standard pattern without edge line). The same result is noted for day conditions.
2. The null treatment had higher speeds than the test pattern without edge lines. This is opposite the results for the day condition.
3. The null treatment had higher speeds than the standard pattern without edge lines.

No statistically significant variability was noted in speeds for this condition.

Summary of Lateral Placement Comparisons

Tables O-7 and O-8 give the results of the vehicle lateral placement comparisons for mean placement and variability. It is evident from a review of the data that in most cases there was no significant difference in driver behavior as measured by mean lateral placement or variability. A closer examination of the tables indicates the following.

Unlimited Sight Distance, Day

It was hypothesized that the lateral placement of vehicles traveling the test section that offered theoretically unlimited sight distance would be less affected by the center line pattern used than vehicles traveling the test section that offered limited sight distance. This assumption stems from the experience of project personnel in driving similar sections of roadway. When one drives a long tangent section with theoretically unlimited sight distance, less dependence is put on either the center line or the edge line for guidance than on a point in the center of the lane far ahead of the vehicle. When a crest vertical curve is approached, and sight distance becomes somewhat limited, this point vanishes and the driver is forced to seek a point closer to the vehicle for guidance. This point is usually the center line or edge line. The results of the study support this theory to a certain degree.

There are no significant differences in the variability of placements within the primary comparisons. In fact, there are no significant differences in the variability of vehicle placements within any of the comparisons made. There is, however, a significant difference at the 1 percent significance level in the mean placement of vehicles when comparing treatment 4 to treatment 5. The value of average placement for treatment 5 (2.240 ft) was 0.47 ft nearer the center line than for treatment 4. This value is somewhat suspect, inasmuch as it is actually significantly different from the placement values for each of the other treatments and seems to indicate that another variable in addition to the center line paint pattern was present. If the type of center line used was the reason for this shift in average placement toward the center of the roadway, it would be reasonable to expect a similar shift in placement under treatment 2 when compared to treatment 3. This, however, was not the case. Average placement for treatment 2 actually shifted 0.19 ft in the opposite direction—away from the center line.

TABLE O-7

MEAN LATERAL PLACEMENT COMPARISONS

CONDITIONS	TREATMENT [a] COMPARISON a	b	DIFF. IN MEAN PLACEMENT [b] (FT)	t-VALUE	STATISTICAL SIGNIFICANCE [c]
Unlim. sight dist.:					
Day	2	3	+0.19	1.451	N.S.
	4	5	+0.47	4.000	0.001
	1	2	−0.08	0.589	N.S.
	1	3	+0.07	0.535	N.S.
	2	5	+0.74	5.801	0.001
Night	2	3	+0.18	1.325	N.S.
	4	5	+0.24	1.842	N.S.
	1	2	−0.60	4.489	0.001
	1	3	−0.42	3.045	0.01
	2	5	+0.60	4.711	0.001
Limited sight dist.:					
Day	2	3	+0.03	0.224	N.S.
	4	5	−0.19	1.518	N.S.
	1	2	+0.22	1.848	N.S.
	1	3	+0.25	1.959	0.05
	2	5	−0.15	1.109	N.S.
Night	2	3	−0.05	0.358	N.S.
	4	5	−0.07	0.507	N.S.
	1	2	−0.14	1.125	N.S.
	1	3	−0.19	1.384	N.S.
	2	5	−0.14	1.035	N.S.

[a] For treatment descriptions see Table O-1 or Table O-2.
[b] $\bar{X}_a - \bar{X}_b$. [c] N.S. = not significant.

TABLE O-8

LATERAL PLACEMENT VARIABILITY COMPARISONS

CONDITIONS	TREATMENT [a] COMPARISON a	b	VARIANCE S_a^2	S_b^2	F-VALUE [b]	STATISTICAL SIGNIFICANCE [c]
Unlim. sight dist.:						
Day	2	3	0.8694	0.8162	1.065	N.S.
	4	5	0.6554	0.6993	1.067	N.S.
	1	2	0.9383	0.8694	1.079	N.S.
	1	3	0.9383	0.8162	1.150	N.S.
	2	5	0.8694	0.6993	1.243	N.S.
Night	2	3	0.7000	1.0420	1.489	N.S.
	4	5	0.9262	0.7598	1.219	N.S.
	1	2	0.9362	0.7000	1.337	N.S.
	1	3	0.9362	1.0420	1.517	N.S.
	2	5	0.7000	0.7598	1.085	N.S.
Limited sight dist.:						
Day	2	3	1.0240	0.8150	1.256	N.S.
	4	5	0.7342	0.8298	1.130	N.S.
	1	2	0.7248	1.0240	1.413	N.S.
	1	3	0.7248	0.8150	1.124	N.S.
	2	5	1.0240	0.8298	1.234	N.S.
Night	2	3	1.1910	1.2300	1.033	N.S.
	4	5	0.9911	1.0266	1.036	N.S.
	1	2	0.7978	1.1910	1.493	0.02
	1	3	0.7978	1.2300	1.542	0.05
	2	5	1.1910	1.0266	1.160	N.S.

[a] For treatment descriptions see Table O-1 or Table O-2. [b] Larger variance divided by smaller variance. [c] N.S. = not significant.

The comparisons between the null treatment (treatment 1) and treatments 2 and 3 were shown to produce no significant differences in terms of either average placement values or variability.

Unlimited Sight Distance, Night

Under the condition of unlimited sight distance at night there were no significant differences in the variability of placements for any of the comparisons. The addition of a center line in treatments 2 and 3 did cause a significant shift in average placement values away from the center of the road when compared to the null condition. This is in conformance with Taragin's studies (*55*), in which he found that for pavement widths between 18 ft and 24 ft wide the typical vehicle path is farther to the right on pavements with a center line marking than it is on similar pavements without pavement markings. Although this same result was expected to be found for each of the conditions studied, this is the only condition in which it occurred.

The introduction of an edge line was shown to cause a shift in average lateral placement of 0.60 ft toward the center line in comparing the results under treatments 2 and 5. This difference was shown to be significant at the 1 percent level.

Limited Sight Distance, Day

There were no differences in the variability of placement values for any of the comparisons studied under the condition of limited sight distance by day. The only difference in driver behavior that was judged statistically significant was in the comparison of average placement values for treatments 1 and 3. In this case, the introduction of a center line caused the average placement value to shift 0.35 ft toward the center line. This is opposite to the expected result, as described previously.

Limited Sight Distance, Night

The condition of limited sight distance at night produced the only significant increases in the variability of placement values that were observed in the study. In comparing the treatments containing a center line and no edge line (treatments 2 and 3) to the null condition (treatment 1), it was found that variability increased significantly with the introduction of the center line. This is contrary to what was expected. The absence of a center line (null treatment) was expected to produce a more variable distribution of placement values due to the lack of guidance information available to the driver.

The average placement values for each of the treatments were closely grouped and did not differ significantly in any of the comparisons.

CONCLUSIONS

A thorough study of all data collected offers no definite evidence for accepting or rejecting the original hypothesis. Although significant differences did occur in the comparisons of speed and lateral placement data, no over-all patterns were evident that would permit categorically concluding that one pattern is better than another based on driver performance. In summary, the findings were:

1. Under the condition of limited sight distance the speed for the test pattern without edge lines was approximately 2.5 mph greater than the standard pattern without edge lines.
2. The introduction of edge lines caused a significant shift in average lateral placement values toward the center line and a more centered position of vehicles in their lane.
3. The introduction of edge lines caused a decrease in variability of both speed and lateral placement values.

APPENDIX P

STOP APPROACH TREATMENTS *

The practice of using post-mounted retroreflective delineators as effective aids for night driving has been an established and accepted procedure for many years. Although delineators are used primarily as guide markers, they can be and are used frequently as warning devices. They are particularly effective when there is a transitional situation that can result in driver confusion. This suggests that perhaps at other locations, such as at a stop approach where there might be driver confusion, similar use might be made of delineators.

Various methods have been used to make the driver aware that he is approaching a stop condition and at the same time make him cognizant of his approach velocity. Included among the methods tested and reporting some degree of success are: transverse striping of the pavement, flashing lights, and rumble strips on the approach. Some of the applications (such as rumble strips in the roadway) stimulate the sense of touch and muscle sensitivity, whereas other treatments (including delineators) provide visual stimuli. However, only limited information is available concerning the effectiveness of these treatments, and conditions warranting their installation are not clearly defined or widely accepted.

As reported in Appendix H, laboratory tests were conducted on several delineation treatments of a stop approach. There are many advantages to laboratory testing over most types of highway field research. For one, it permits rapid evaluation of new systems under controlled conditions, resulting in potential savings of time and expense. However, the actual value of a delineation system can be verified only by observing the motorist's reaction to it under field conditions.

Through the laboratory testing, it was found that certain colors and spacings of post delineators in the stop approach were more effective than others. It was the intent, then, for this task to take field measurements of average speed and speed variance for three of the laboratory-developed treatments. If speed relationships among treatments are similar to those found in the laboratory, this study will lend support to the laboratory methodology and its findings.

* By Theodore Jennings, Graduate Student, Bureau of Highway Traffic, The Pennsylvania State University.

PURPOSE OF STUDY

The purpose of this study was to evaluate the effect of post-mounted delineators on nighttime approach speeds at a selected rural stop approach. Specifically, the study was concerned with the evaluation of the base condition (no delineators) and three selected post delineator treatments. The evaluation was based on the effects that various treatments exhibit on driver behavior, measured in terms of average speed and variance of vehicle speeds in the stop approach area.

The stop approach field study was to serve two distinct purposes: (1) to test the hypothesis that selected delineation systems would reduce average speed and vehicle speed variability in the stop approach area; and (2) to validate, with respect to color and spacing of delineators, a laboratory methodology that was derived to short-cut (or, alternatively, to permit expedient decisions) the selection of performance-effective delineation systems.

SCOPE

The object of this study was to determine the effect of post-mounted delineators on mean speed and vehicle speed variability in the stop approach area. To measure this effect, a rural site was selected and field observations were made before and after the delineation treatments were installed. Except for the delineation treatments, all other road conditions were kept constant during the sampling so that if there were significant differences in the speed profiles and variability of driver behavior, it could be assumed that the change(s) was due to the effect of the treatment(s).

From among the several laboratory-evaluated post delineator spacings, two—conventional spacing and geometric spacing—were selected for use in this field study. The following definition for each was applied both in the laboratory testing and throughout the field study:

1. *Conventional Spacing*—A spacing of 200-ft increments between posts on tangents was found to be the most common spacing among the several states surveyed in developing a state-of-the-art for the project. Thus, the conventional spacing of 20 ft between posts, with the restriction that the first post was always 10 ft from the STOP sign, was adopted for this study.
2. *Geometric Spacing*—Indicates geometrically closer spacing of posts as the STOP sign is approached. Again, the first post was 10 ft from the STOP sign. Successive placement of each post was then at a distance double the previous interval, with the restriction that no two successive posts would be more than 200 ft apart. Thus, the actual placements, in terms of distance from the STOP sign, were 10, 20, 40, 80, 160, 320, 520, 720, 920, and 1,120 ft. When red delineators were used the red was carried to the 720-ft point and then switched to clear.

The four treatments studied were as follows:

1. Treatment 1—Base condition with no delineation.
2. Treatment 2—Red delineators spaced according to the geometric spacing described.
3. Treatment 3—Red delineators with a uniform spacing of 200 ft.
4. Treatment 4—Crystal delineators spaced geometrically.

Figures P-1, P-2, and P-3 show the site at night and in the daytime.

STUDY SITE

The site selected for this study was the junction of US 322 and Pa. 144, 13 miles east of State College, at Potters Mills, Pa. Both US 322 and Pa. 144 are two-lane highways, surfaced with asphaltic concrete, and have shoulders constructed of earth.

Southbound traffic on Pa. 144 must stop at the intersection with US 322; i.e., the STOP sign is placed on Pa. 144. A STOP AHEAD warning sign is located approximately 1,200 ft north of the intersection on Pa. 144. The intersection, which terminates Pa. 144, is a "skewed tee." Figure P-4 shows the intersection layout.

The selected site is in a rural area, even though the small community of Potters Mills is located along Pa. 144 near its intersection with US 322.

It was particularly desirable to sample a driver population that included nonlocals. The assumption was that nonlocal drivers would not exhibit a conditioned response to the intersection through familiarity or habitual use. Pa. 144 provides a direct route from Interstate 80 near Milesburg, Pa., to Harrisburg, Pa. It was assumed that some nonlocal trips would be attracted through the selected site for this reason. This was partially substantiated by a relatively high percentage of trucks; however, practically no out-of-state cars were recorded during sampling.

EXPERIMENTAL PROCEDURE

Data Collection

Stop approach spot speeds were taken by radar at points 500 ft and 200 ft from the STOP sign. Spot speeds of nearly 100 free-flowing vehicles were recorded for each of the four stop approach conditions. Care was taken to ensure that only free-flowing vehicles were recorded. Observations were synchronized in such a manner that individual vehicles were given the same number at both spot speed stations. This method of recording permitted tracing of vehicle speeds both individually and collectively in the stop approach area.

A vehicle was considered to be free flowing only when there were no other vehicles influencing the speed at which the vehicle approached the STOP sign. To reduce, if not eliminate judgment, speed recorders were instructed to take readings only when the approach was clear from the 500-ft point to the STOP sign. Thus, any vehicle whose performance was influenced by obvious outside forces was disregarded. Also disregarded were vehicles making right turns and those turning for a better approach angle to the intersection.

Data Analysis

Analysis of the data was made using The Pennsylvania State University's computer library program ANOVUM (Analysis of Variance Method of Unweighted Means).

The analysis was performed on the means for each cell (each sample in this study), and each sum of squares was multiplied by the harmonic mean of the number of observations per cell.

Bartlett's test for homogeneity of variance was computed for each group of data. Included in the Bartlett's test printed output were: chi-square values, degrees of freedom, and probability of homogeneity.

An analysis of variance summary table, including treatment names, sums of squares, degrees of freedom, mean squares, and F-ratios and their probabilities, was also provided in computer print-out form.

If the F-ratio indicated significant differences between sample means, the next step was to determine the smallest difference that could exist between two significantly different sample means. Because the analysis of variance involved more than two samples, the widely accepted Duncan's multiple-range test was used.

Data Reduction

The data were divided into three separate groups for analysis, as follows:

Group 1 was made up of all the spot speed observations taken at the 500-ft station. Each of the four samples was fed into individual cells of the computer, forming a group of four cells. The group of data was then analyzed according to the foregoing method of analysis.

Group 2 contained only the speed observations taken at

Figure P-1. Study site as seen in daylight from 500 ft from STOP sign.

Figure P-2. Study site as seen at night from 250-ft from STOP *sign without delineators.*

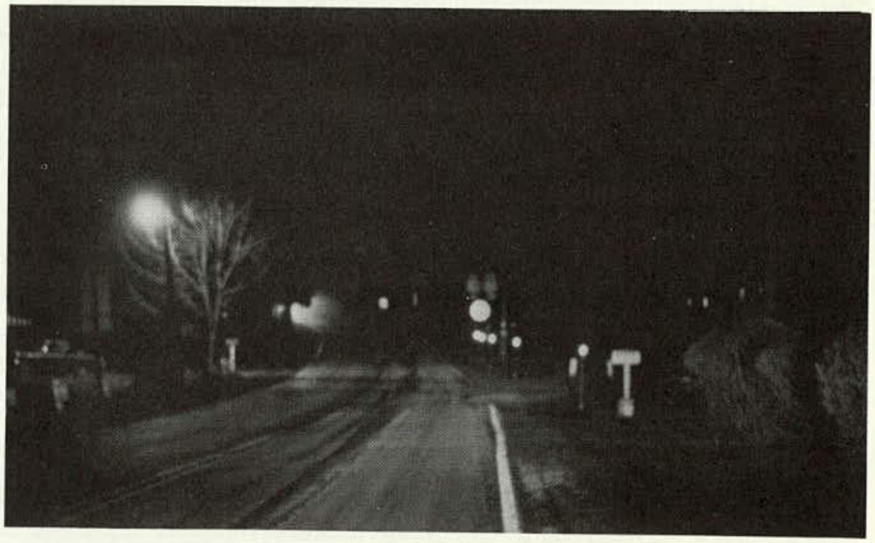

Figure P-3. Study site as seen at night from 250 ft from STOP *sign with delineators.*

the 200-ft station. The procedure used for analysis was identical to that used for group 1.

Group 3 was comprised entirely of speed differentials; i.e., individual vehicle speed reductions between the two stations. Again, each sample was wholly contained in a single cell and analyzed in the same manner as the two preceding groups.

Figures P-5 through P-8 show speed distributions for each of the four treatments.

DISCUSSION OF RESULTS

A summary of the results from the computer processing of the data is given in Tables P-1, P-2, P-3, and P-4. Tables P-1, P-2 and P-3 give results of the analysis performed on the three groups of data described previously. Each of these tables contains four separate, but related, sections of statistical results, as follows:

Section I—Average speed, sample size, variance, and standard deviation for each of the four treatments.

Section II—The results from Bartlett's test for homogeneity of variance.

Section III—An analysis of variance summary, including a computed *F*-ratio and the level of significance of probable differences among sample means.

Section IV—Because the probability of significantly different means in each of Tables P-1, P-2, and P-3 was beyond the 0.05 level, it was necessary to determine the least significant differences.

Results of Spot Speed Comparisons

Tables P-1, P-2, and P-3 show that significant changes in the mean speeds did occur. Table P-4 indicates which treatments had significantly different mean speeds and which speed differentials were significantly different.

Tables P-1 and P-4 show that Treatments 3 (red delineators, 200-ft spacing) and 4 (crystal delineators, geometric spacing) had significantly lower mean speeds than Treatments 1 (no delineation) and 2 (red delineators, geometric spacing) at the 500-ft station. It was concluded that Treatments 1 and 2 had homogeneous mean speeds and Treatments 3 and 4 had homogeneous mean speeds at the 500-ft station.

Emphasis should be placed on the results at the 200-ft station because it is closer to the STOP sign than the 500-ft station. Therefore, control of mean speed and vehicle speed variability are thought to be more critical at this location and more closely related to approach treatment.

Mean speed comparisons at the 200-ft station revealed uniformly lower mean speeds for Treatments 2, 3, and 4. However, only the Treatment 4 mean speed was significantly lower than that computed for Treatment 1. Treatments 2 and 3 showed a reduced mean speed, but not significantly different from the mean of either Treatment 1 or Treatment 4.

Although the mean speeds were reduced by all three treatments where delineators were physically present in the stop approach area, only Treatment 4 can be concluded to have significantly reduced the mean speed at both spot speed locations. The results support the conclusion that Treatment 4 mean speed was significantly lower than the Treatment 1 mean speed; also, that Treatments 2 and 3 had mean speeds between those of Treatments 1 and 4 and they could not be considered to be significantly different from each other or from the mean speeds of Treatment 1 or Treatment 4.

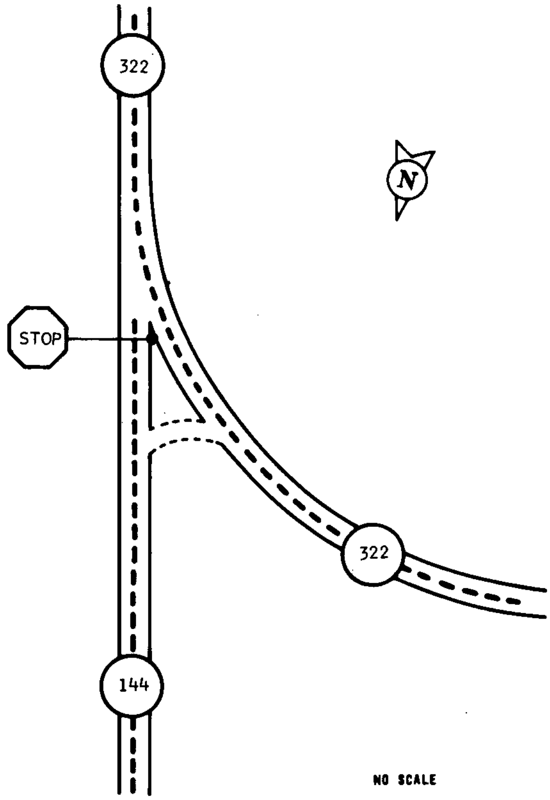

Figure P-4. Layout of study site.

Variability Comparisons

Treatment comparisons of variability showed no significant differences among the four treatments. Section II of Tables P-1, P-2, and P-3 gives the probability of significant differences among the variances for each of the three groups of data. Obviously, there are differences shown among the individual variances, but the significance level was such that they cannot be said to be significantly different with confidence. The variability, unlike the mean speeds, did not show any apparent trend.

CONCLUSIONS

The conclusions resulting from this field study can be stated as follows:

1. Average speed was significantly reduced through the application of post delineators in the stop approach area.
2. Vehicle speed variability was not significantly affected by the delineator treatments.
3. Because there was no evidence of reduced un-

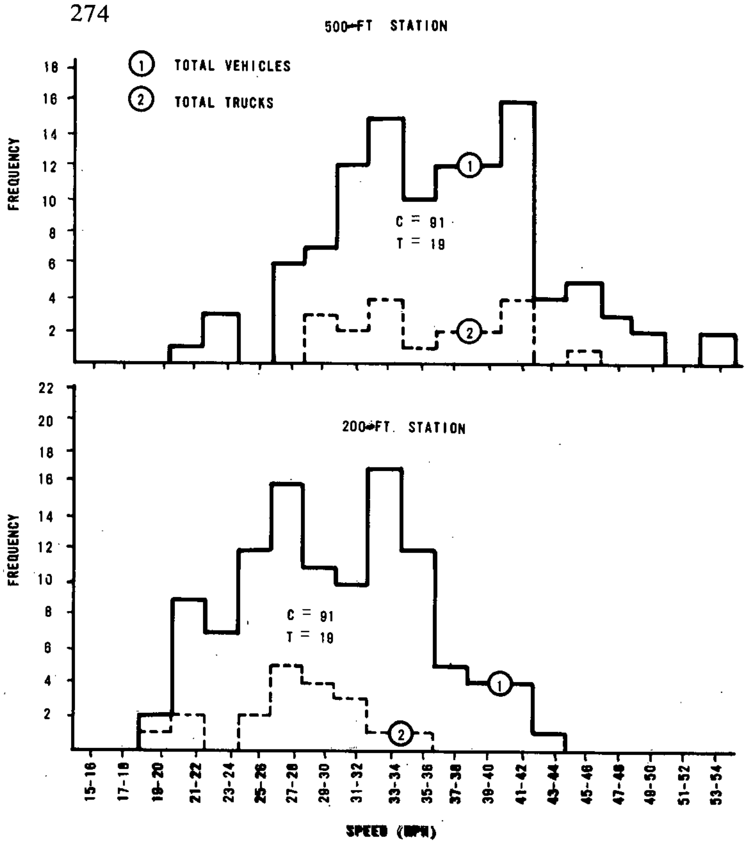

Figure P-5. Speed distributions, Treatment 1 (base).

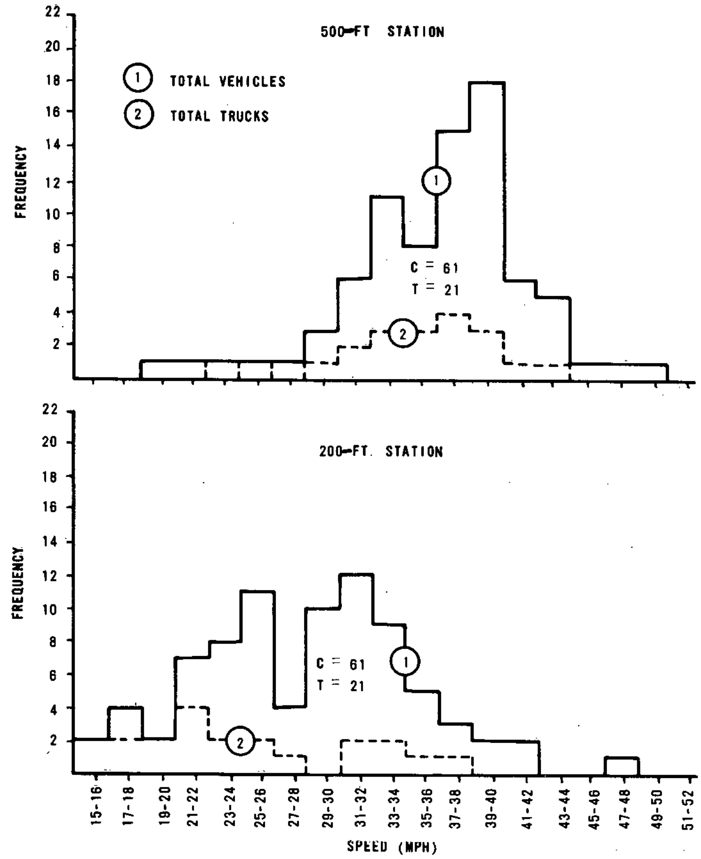

Figure P-6. Speed distributions, Treatment 2.

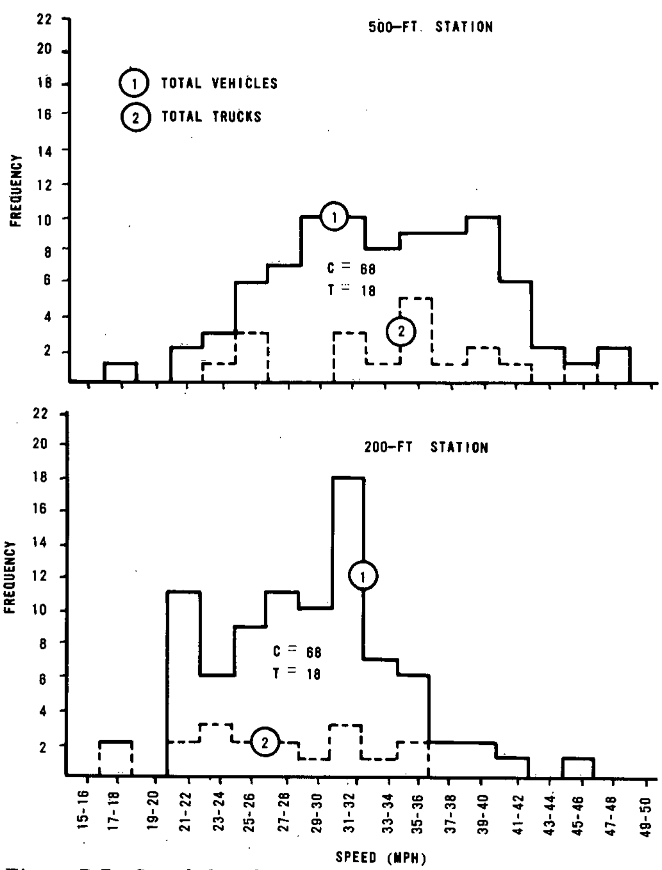

Figure P-7. Speed distributions, Treatment 3.

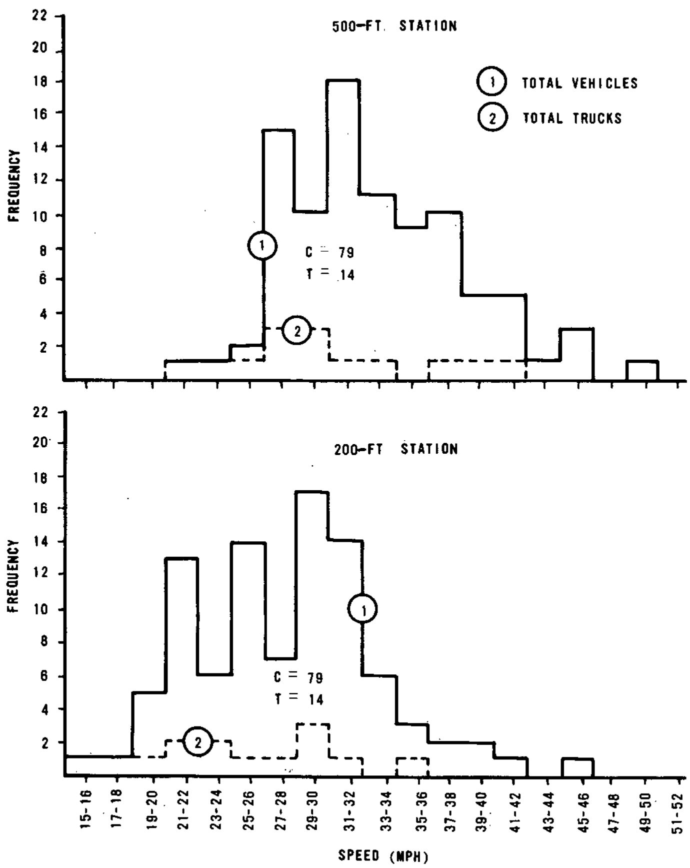

Figure P-8. Speed distributions, Treatment 4.

TABLE P-1

STATISTICAL SUMMARY OF 500-FT STATION DATA

I

TREATMENT	MEAN SPEED (MPH)	SAMPLE SIZE (NO.)	VARIANCE	STD. DEV.
1 (base)	37.13	110	37.18	6.10
2	36.85	82	20.72	5.54
3	33.72	86	39.83	6.31
4	33.63	93	29.73	5.45

II Bartlett's Test for Homogeneity of Variance

Degrees of freedom = 3
Chi square = 2.7128
Probability = 0.438060

III Analysis of Variance Summary Table

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-RATIO	PROB.
Total	13,695	370	—		
Among groups	1,034	3	344.61	9.989	<0.001
Within groups	12,661	367	34.50		

IV Duncan's Multiple-Range Test

Duncan's $LSD_{0.05} = D_{0.05}\sqrt{\frac{MS_w}{n_h}}$; where: $D_{0.05} = 3.32$, $MS_w = 34.50$, $n_h = 92$

$= 2.03$ mph

Duncan's $LSD_{0.01} = 2.64$ mph

TABLE P-2

STATISTICAL SUMMARY OF 200-FT STATION DATA

I

TREATMENT	MEAN SPEED (MPH)	SAMPLE SIZE (NO.)	VARIANCE	STD. DEV.
1 (base)	30.51	110	30.64	5.54
2	28.98	82	44.67	6.68
3	28.93	86	31.78	5.64
4	27.76	93	34.16	5.84

II Bartlett's Test for Homogeneity of Variance

Degrees of freedom = 3
Chi square = 3.9313
Probability = 0.268982

III Analysis of Variance Summary Table

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-RATIO	PROB.
Total	13,190	370	—		
Among groups	388	3	129.40	3.710	0.012
Within groups	12,802	367	34.88		

IV Duncan's Multiple-Range Test

Duncan's $LSD_{0.05} = D_{0.05}\sqrt{\frac{MS_w}{n_h}}$; where: $D_{0.05} = 3.32$, $MS_w = 34.88$, $n_h = 92$

$= 2.04$ mph

Duncan's $LSD_{0.01} = 2.65$ mph

TABLE P-3

STATISTICAL SUMMARY OF SPEED DIFFERENTIALS

I

TREATMENT	MEAN DIFFERENTIAL (MPH)	SAMPLE SIZE (NO.)	VARIANCE	STD. DEV.
1 (base)	6.62	110	14.37	3.79
2	7.88	82	21.37	4.62
3	4.79	86	19.51	4.42
4	5.87	93	15.64	3.95

II Bartlett's Test for Homogeneity of Variance

Degrees of freedom = 3
Chi square = 4.7745
Probability = 0.189077

III Analysis of Variance Summary Table

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-RATIO	PROB.
Total	6,821	370	—		
Among groups	428	3	142.76	8.195	<0.001
Within groups	6,393	367	17.42		

IV Duncan's Multiple-Range Test

Duncan's $LSD_{0.05} = D_{0.05}\sqrt{\frac{MS_w}{n_h}}$; where $D_{0.05} = 3.32$, $MS_w = 17.42$, $n_h = 92$

$= 1.44$ mph

Duncan's $LSD_{0.01} = 1.86$ mph

TABLE P-4

STATISTICAL SUMMARY OF DATA GROUPS

I Mean Speed

TREATMENT	DISTANCE FROM STOP SIGN (FT)	MEAN SPEED (MPH)	SIGN. DIFF. FROM TREAT. NO.	VARIANCE	SIGN. DIFF.
1 (base)	500	37.13	3, 4	37.18	No
2	500	36.85	3, 4	30.72	No
3	500	33.72	1, 2	29.83	No
4	500	33.63	1, 2	29.73	No
1 (base)	200	30.51	4	30.64	No
2	200	28.98	None	44.67	No
3	200	28.93	None	31.78	No
4	200	27.76	1	34.16	No

II Mean Speed Differential

TREATMENT	SPEED DIFF. (MPH)	SIGN. DIFF. FROM TREAT. NO.	VARIANCE	SIGN. DIFF.
1 (base)	−6.62	3	14.37	No
2	−7.88	3, 4	21.37	No
3	−4.79	1, 2	19.51	No
4	−5.87	2	15.64	No

certainty, as measured in terms of speed variance, it is concluded that the average speed reductions, although encouraging, do not constitute enough evidence to declare the study hypothesis supported.

4. Clear delineators at geometric spacing appeared to be more effective STOP sign cues than the red delineators (measured in terms of mean speed). The finding that clear delineators were stronger visual cues than red supports the laboratory findings (discussed in Appendix H).

5. Unfortunately, the effect of post spacing (conventional vs geometric) can be considered only on the basis of red delineators; this is unfortunate in the sense that red delineators were found to be ineffective at both spacings, and because only one treatment (Treatment 4) involved the use of clear delineators. Therefore, comments regarding laboratory methodology on development of effective spacing for post-mounted delineators cannot be made on the basis of results from this study.

APPENDIX O

VALIDATION OF INTERMEDIATE CRITERIA ON RURAL HORIZONTAL CURVES *

Most studies of highway improvement projects seek to examine the relationship between such improvements and accident rates. An attempt is made to correlate the accident rates with treatment types so as to arrive at an over-all measure of treatment performance. However, there are many problems involved when accident rates are used to differentiate among treatments. One problem is that heavy reliance on accident reports is required. Unfortunately, the reliability of accident reporting varies considerably from place to place and from time to time. Another problem with this approach is the considerable time required to reach reliable conclusions. This can be especially critical if the proposed improvement is not already an adopted practice. Also, new products or concepts cannot be evaluated without changing the driving context and possibly exposing drivers to additional dangers. Thus, several researchers have turned to erratic maneuvers and intermediate measures in an attempt to overcome the difficulties involved with the accident records approach. Examples of erratic maneuvers are sudden braking, sudden lane change, vehicle weaving, and backing up. Examples of intermediate measures are vehicle speed, placement, acceleration, and deceleration.

The rationale behind the use of these measures is that they are more easily obtained than accident histories and so treatment effectiveness can be evaluated in a relatively short period of time. It is implicitly assumed, however, that if a particular treatment in some way affects these measures it will also affect accident rates. However, this assumption has never been statistically validated.

This study, therefore, seeks to correlate various intermediate performance measures with accident rates on horizontal curves. The measures that are to be correlated with accidents are statistics derived from vehicle speed and lateral placement.

* By Anthony M. Pagano, Research Assistant, The Pennsylvania State University.

THE VULNERABILITY CONCEPT

Before intermediate criteria can be studied, it must be known at least intuitively which measures to examine. A logical starting point is the analysis of vulnerabilities and confrontations as discussed by Goeller (*379*). He says:

> . . . A driver, on the basis of his perceptions of the events happening around him, makes decisions and takes actions which usually produce safe driving. But sometimes the driver fails to perceive a traffic event or makes a misjudgment, thereby incurring a hazard and becoming momentarily vulnerable to a potential collision; e.g., by entering a "blind" intersection or by following too closely. Whenever he does so, he has committed a *vulnerability*, an act which could ultimately result in a collision if, say, some other driver made a mistake or did not behave as expected. Thus, a driver's *vulnerability rate*, defined as vulnerabilities per mile, should be an operationally meaningful index of his unsafe behavior or impairment.

Goeller describes four types of vulnerabilities:

1. Perceptual vulnerabilities—failure to observe some driving-related event that may cause the driver to face a hazard.
2. Skill vulnerabilities—"The driver can incur a hazard through neglect of some basic driving skill in executing his decision."
3. Chance vulnerabilities—e.g., tire blowout or other vehicle failures.
4. Judgment vulnerabilities—an incorrect decision on the part of a driver that may cause him to face a hazard.

Goeller uses these vulnerabilities to predict collision rates. He says that if it is known how often and under what circumstances some dangerous vulnerability occurs ". . . then we can use our model to predict how many collisions could be avoided if that vulnerability were eliminated or reduced."

Of crucial importance in the modeling of collisions is what he calls the "juxtaposition phase." In this phase the concern is with predicting the number of collisions that can be expected from a given vulnerability rate. He says: "The interactions taking place in the juxtaposition phase transform a vulnerability into one of two possible situations: a *confrontation* with danger occurs, or the vulnerability proves a non-dangerous hazard." Goeller defines a confrontation as an ". . . imminent but not yet inevitable collision." He says:

> The expected number of confrontations for a driver in a given mile depends on (1) the number of times he makes himself vulnerable to a particular type of danger, (2) the number of times that danger actually occurs, and (3) the likelihood that these juxtapose (coincide) in time and space. The first quantity is clearly the *vulnerability rate* (or a component thereof), the second is the *exposure* to danger, and the third is the juxtaposition probability.

An example by Goeller illustrates how the vulnerability concept can be used to predict the number of confrontations for a particular driver. Suppose a driver runs off the road just once in a mile and that he travels 0.1 mile on the shoulder before he finally gets back on the road. Clearly his vulnerability rate is 1, because he runs off the road once in a mile. If there are two fixed objects along the shoulder, his exposure is two. Goeller says that the juxtaposition probability is 0.1, "since the driver stays off the roadway for 0.1 mile; therefore, he will confront a particular fixed object only if he goes off the road within the particular 0.1-mile strip before the fixed object. . . ." So, the number of confrontations that is expected due to the vulnerability of running off the road is:

$$\left(\begin{matrix}\text{1 time}\\ \text{off the road}\end{matrix}\right)\times\left(\begin{matrix}\text{2 fixed object}\\ \text{dangers}\end{matrix}\right)\times\left(\frac{1}{10}\right) = \tfrac{1}{5}\,\frac{\text{confrontation}}{\text{mile}}$$

To transform the confrontations into collisions, Goeller defines the evasion phase of the collision chain of events. If evasion is successful, a near miss occurs. However, if the evasion is not successful, an actual collision results. Thus, the number of collisions per mile can be obtained from the number of confrontations per mile, the number of near misses per mile, and the chances that the driver can successfully avoid a collision, which is called the *evasion probability*. The number of near misses is equal to the number of confrontations times the evasion probability.

If, then,

CON = number of confrontations per mile;
NM = number of near misses per mile;
COL = number of collisions per mile;
V = number of vulnerabilities per mile;
E = exposure;
J = juxtaposition probability; and
EVP = evasion probability,

$$\begin{aligned}\text{COL} &= \text{CON} - \text{NM}\\ &= \text{CON} - \text{CON(EVP)}\\ &= \text{CON}(1 - \text{EVP})\\ &= V\,E\,J(1 - \text{EVP})\end{aligned} \tag{Q-1}$$

Thus, Goeller's model could be used to predict the expected collision frequency of individual drivers if all of the foregoing factors could be estimated. Collision rates could be reduced by reducing driver vulnerability rates, reducing exposure, reducing juxtaposition probabilities, and increasing the evasion probability.

Rather than predicting the accident rates of particular drivers, however, Goeller's model can also be used to predict the total number of accidents that can occur at a particular location. Assume that for some given horizontal curve, the average driver sometimes commits the vulnerability of running off the road. Some drivers may commit more vulnerabilities than others, but only the average rate is necessary for this analysis. If the average vulnerability rate is multiplied by the total number of vehicles passing through the curve in a year, the total number of vulnerabilities committed at that curve can be estimated. Suppose 100 vulnerabilities are committed at this curve per year. Also assume that six posts are located along the shoulder of the road, equally spaced every 100 ft, and the curve is 600 ft long. If the average vulnerable driver drives 50 ft along the shoulder before recovering, the juxtaposition probability is 50 ft/600 ft = 1/12.

The total number of confrontations per year can be obtained from

$$\begin{aligned}\frac{\text{CON}}{\text{year}} &= \frac{V}{\text{year}} \times E \times J\\ &= \frac{100}{\text{year}} \times 6 \times \frac{1}{12}\\ &= 50\ \text{CON/year}\end{aligned} \tag{Q-2}$$

If it is assumed that either the evasion probability for this curve is constant from one vulnerable driver to another, or that at least it is independent of a given driver's vulnerability rate, the total number of accidents can be predicted for this horizontal curve. Assume that the probability of evasion is 0.9. Because

$$\frac{\text{Accidents}}{\text{year}} = \frac{\text{CON}}{\text{year}} - \frac{\text{NM}}{\text{year}} \tag{Q-3}$$

and

$$\frac{\text{NM}}{\text{year}} = \frac{\text{CON}}{\text{year}}\ \text{E V P} \tag{Q-4}$$

$$\begin{aligned}\frac{\text{Acc}}{\text{year}} &= \frac{\text{CON}}{\text{year}}\ (1 - \text{E V P})\\ &= \frac{50\ \text{CON}}{\text{year}}\ (1 - 0.9) \doteq 5\ \text{Acc/year}\end{aligned} \tag{Q-5}$$

However, the interest in this study is in estimating the relative hazard of various horizontal curves, rather than the total number of accidents. The total number of accidents is an inadequate measure of hazard because it depends on the ADT and the length of the curve. Two curves that exhibit the same total number of accidents could involve different degrees of hazard because the average vulnerability rate, as well as the exposure, could differ, all other factors being the same. So, if the total number of accidents and the total number of vulnerabilities are divided by both the total number of vehicles passing through the curve in a year and the length of the curve, then a true measure of hazard is obtained that can be used to compare one curve to another. Thus:

$$\frac{\text{Acc}}{\text{veh-mile}} = \frac{V}{\text{veh-mile}} E\,J\,(1 - \text{E V P}) \qquad \text{(Q-6)}$$

Thus, the relative hazard of various horizontal curves can be estimated by estimating the vulnerability rate per vehicle-mile, the exposure, the juxtaposition probability, and the evasion probability for each curve. However, there are different types of vulnerabilities that can occur at curves, and each must be modeled in the same fashion as the run-off-the-road vulnerability.

The types of vulnerabilities that can occur on horizontal curves can be enumerated through an examination of the types of accidents that occur there. Basically, these are single-vehicle run-off-the-road accidents, two-vehicle opposite-direction sideswipe and head-on accidents, single-vehicle overturns, and rear-end accidents involving two vehicles. The type of vulnerability that would cause run-off-the-road single-vehicle accidents is, of course, the run-off-the-road type of vulnerability. Thus, the number of vehicles encroaching on the edge line could be used to model this type of accident. Opposite-direction sideswipe and head-on accidents manifest themselves through the vulnerability of vehicles encroaching on the opposing lane. The vulnerability that could cause rear-end accidents is rapid vehicle deceleration. A combination of rapid deceleration and vehicle encroachment on edge lines and center lines could account for single-vehicle accidents in which the vehicle overturned on the curve. Rapid vehicle deceleration could also be an indirect factor in run-off-the-road accidents and opposite-direction sideswipe and head-on accidents.

Thus, it may be possible to use Goeller's model to predict the expected accident frequency of various horizontal curves. Each of these accident types could be modeled in much the same manner as the run-off-the-road type of accident. Vulnerability rates could be calculated for vehicles passing through the curves under consideration, and the corresponding measures of exposure, juxtaposition probabilities, and evasion probabilities could also be calculated. Delineation treatments could be evaluated by observing how they influence each of these factors. Thus, a means is available to test treatment effectiveness without waiting for the prolonged period in which accident histories evolve.

There are, however, numerous problems involved with utilizing this approach to test treatment effectiveness and evaluate the relative hazard of various horizontal curves. In the simplified example, exposure was measured by the number of posts along the side of the road. Attempting to measure exposure in the real world would not be as simple. Posts are not equally spaced, nor are they the same distance from the road edge. Sheer drops and cliffs cannot simply be counted and they may not be present in the same section of each curve. Some measure must be derived that integrates different types of hazards into a single measure of exposure. In addition, the measure of exposure for opposite-direction sideswipe and head-on accidents is the traffic flow in the other lane, which is not constant from one hour to the next. Thus, some sort of constantly changing measure of exposure must be derived for inclusion in the model of these types of accidents. Rear-end accidents involve another problem, because the vulnerability of following too closely must be included in the model. The measure of exposure thus becomes the rapidity of deceleration. The juxtaposition of rapid deceleration and following too closely produces a confrontation that can result in a rear-end accident. The probability of these two vulnerabilities occurring together is dependent on the volume of traffic; thus, some constantly changing measure must also be derived for this type of accident.

The simple example assumed that the juxtaposition probability was constant; i.e., vulnerable drivers traveled the same distance on the shoulder before recovering. One way to resolve this difficulty is to calculate some average value for this quantity. However, it must be assumed that vulnerability rates and juxtaposition probabilities are independent for individual drivers, which does not seem valid because drivers who commit more vulnerabilities probably drive farther on the shoulder or in the other lane. This quantity can also change from one section of a curve to another. For example, it may be larger at the midpoint than at either end.

Finally, there is no justification for believing that the evasion probability is either constant or independent of vulnerability rate. Drivers who commit more vulnerabilities probably have evasion probabilities that are lower than those of other drivers.

These problems are difficult but not insurmountable. Conceivably, some estimate of these quantities could be made and independence could be assumed without appreciably affecting the results. However, the amount of time needed to collect data on all of these factors, and measure them accurately, would severely limit any attempt to study them. Another approach would be to ignore the exposure, the juxtaposition probability, and the evasion probability, and evaluate horizontal curves solely on the basis of vulnerabilities. It would seem, at any rate, that there would be a high correlation between vulnerability rates and accident rates and thus treatments could be evaluated on how they reduce vulnerabilities. But even this measure involves many problems of measurement. How shall it be decided whether a car is vulnerable or not? That is, must the driver be completely off the edge of the road, or 3 ft from the edge, or must his tires be just touching the edge line for him to be vulnerable to the run-off-the-road-type accident?

The vulnerability of encroaching on the other lane involves this same problem. Also, how rapid is too rapid deceleration? Thus, the measurement of vulnerabilities on horizontal curves involves many subjective judgments and the line between "vulnerable" driving and "safe" driving is a fine one indeed.

Another approach is to count the number of near misses that occur on horizontal curves. Near misses occur more frequently than accidents and do not involve as many subjective judgments as vulnerabilities. Goeller defines near misses as narrowly evaded collisions and he believes that there are many advantages in collecting these data and studying them. It should be noted that near-miss studies have been of great value in improving air safety. Perkins and Harris (*377*) conducted a study of near misses at intersections. They call these near misses "traffic conflicts" and say that "a traffic conflict is any potential accident situation." They go on to say that there are two types of traffic conflicts: ". . . evasive actions of drivers and traffic violations. When confronted with an impending accident situation, a driver takes evasive action to avoid collision. Evasive actions by drivers are evidenced by vehicle braking or weaving as attested by light indication or lane change." They say that traffic violations are defined in accordance with the Uniform Traffic Code: "A traffic violation is a traffic conflict, a potential accident situation; no other vehicle need be in close proximity to the violation."

They also state: "A traffic accident, the collision of vehicles, is thus viewed as a traffic conflict with the addition of a driver, road, or vehicle fault: the driver was not paying attention, the road was slippery, the brakes failed."

An example of a conflict situation at an intersection is the left-turn conflict. This is defined as "a situation in which a left-turn vehicle crosses directly in front of an opposing through vehicle." They say: "The criterion of the conflict is the evasive action—braking or weaving—of the through vehicle."

It would seem that near misses would be highly correlated with accident rates on horizontal curves. Thus, they may be used to evaluate treatment effectiveness. However, unlike the situation at intersections in which near miss occurrence is fairly common, they do not occur frequently on horizontal curves, so a large expenditure in time and money is needed to get statistically significant results. Thus, near misses are inadequate measures of hazard on horizontal curves because of the difficulty involved in obtaining an adequate sample.

DERIVATION OF INTERMEDIATE CRITERIA

In view of the difficulties involved in studying near misses and vulnerabilities on horizontal curves, it was believed that more fruitful results could be obtained through an examination of intermediate criteria, which are statistics derived from vehicle speeds and placements. Whereas considerable time and effort must be spent in obtaining large enough samples of near misses and vulnerabilities, no such problem exists when intermediate criteria are studied on horizontal curves. Thus, curves can be evaluated in a relatively short time. Intermediate criteria are easy and practical to collect and do not involve as many subjective judgments as the other two measures. These criteria can be derived from analysis of the types of vulnerabilities that occur on horizontal curves.

As mentioned earlier, one of the problems involved with the study of vulnerabilities is the subjective judgments involved as to when a particular driver is driving vulnerably. There seem to be different degrees of vulnerability. The driver who is driving completely on the shoulder of the road is surely more vulnerable to an accident than one whose front wheel just touches the edge line. Thus, the farther vehicles deviate from some ideal path through a curve the more vulnerable they are to accidents. This ideal path is not known at the present time. However, it can reasonably be assumed that the path of the average driver approximates this path. The likelihood of a run-off-the-road accident increases as the deviation from the ideal path approaches the road edge and the likelihood of an opposite-direction sideswipe or head-on accident increases as the deviation approaches the other lane. Thus, the farther a vehicle is from normal placement through the curve, the more vulnerable it probably is to an accident. Thus, if P_i is the lateral placement of the ith vehicle and $\bar{P}$ is the lateral placement of the average vehicle, the statistic $(P_i - \bar{P})$ yields the deviation in placement from normal driving for a particular vehicle. This statistic would be sometimes negative and sometimes positive depending on whether the vehicle is to the right or to the left of the average vehicle placement. So, for each vehicle the statistic $(P_i - \bar{P})^2$ can be used to give all deviations from normal placement a positive value. These deviations are summed and divided by the total number of observations to yield the statistic $\frac{\Sigma(P_i - \bar{P})^2}{n}$, which is nothing more than the variance of placement.

It might be most fruitful to calculate vehicle placement and the corresponding placement variance as vehicles travel throughout the curve. This, however, would involve a rather large expenditure of both time and money, because so many observations are needed per vehicle per location. Thus, vehicle placement variance was taken only at the midpoint of the curve because it was believed that the effect of the curve on vehicles would be the greatest at this point.

The variance of placement at the midpoint, however, is not an adequate measure of the potential hazard of different horizontal curves. Conceivably, two horizontal curves that exhibit the same accident rate may exhibit a different variance of placement at the midpoint due to other factors. Placement variance is affected by the geometrics of a given curve; that is, degree of curvature, amount of grade, lane width, and amount of superelevation may affect the placement variance at the midpoint. Different vehicle types and widths and different driver populations may also affect the placement variance. Although these factors could conceivably affect accident rate, it does not seem justified to believe that they affect placement variance and accident rate in the same manner. Thus, there is need to normalize the placement variance at each curve. The approach in this study was to calculate the placement variance at the PC (point of curvature—the point where tangency ends and curvature begins) and form a ratio of the variance at the midpoint over the variance at the PC. The variance at the PC provides an indication of how drivers act before they reach the curve and the variance at the midpoint indicates how the drivers react as they negotiate the curve. This ratio is a dimensionless number that reduces the effect of the foregoing factors and produces a single measure that is indicative of the pure effect of the curve on driver behavior. It is hypothesized that this ratio and accident rates correlate in a positive fashion on horizontal curves.

The other vulnerability that can occur on horizontal curves is rapid vehicle deceleration. It should be recalled that rapid deceleration is a direct factor that influences rear-end accidents at horizontal curves and an indirect factor in vehicle overturning, run-off-the-road, and opposite-direction sideswipe and head-on accidents. The statistic used in this study was:

$$\frac{(\bar{S}_{PC} - \bar{S}_M)\bar{S}_{PC}}{L} \qquad \text{(Q-7)}$$

in which

$\bar{S}_{PC}$ = mean speed at PC, in miles per hour;
$\bar{S}_M$ = mean speed at midpoint, in miles per hour; and
L = length, in miles, from PC to midpoint.

This statistic is an average deceleration rate and is in terms of miles per hour per hour. A better statistic might have been to derive the average deceleration rate for each vehicle passing through the curve. This, however, was deemed not feasible because of the great difficulty in collection of data.

PROCEDURE

Selection of Test Sites

The correlation of intermediate criteria with accident rates requires test sites that exhibit a wide variation in accident rates. In order to obtain these sites, questionnaires were sent to accident analysis teams of the Pennsylvania Department of Transportation in districts throughout the state. The questionnaires asked each team to indicate which horizontal curves in its district exhibited high accident rates, were located on rural, two-lane roads, and did not have any major changes in their characteristics during their accident histories. Accident histories were obtained from the Pennsylvania Department of Transportation for all of the sites received on the basis of the questionnaire. Curves were also chosen in Centre County, Pa., from accident histories provided by the Pennsylvania Department of Transportation. A sample of nine horizontal curves was then selected so as to provide a wide variation in accident rates.

Description of Test Sites

All of the nine test sites were two-lane roads located in rural areas. Five of the sites were located in Centre County; the others were located in the vicinity of Harrisburg, Scranton, Gettysburg, and Stroudsburg. Thus, no one geographic area was used. Accident rates varied from 5.03 to 77.87 per million vehicle-miles. Average daily traffic for the curves varied from 2,370 to 5,270. Radius of curvature varied from 143 to 763 ft. Thus, the sample consisted not only of a wide variation in accident rate but also of a variation in types of driver populations, geometric characteristics, and vehicular volume.

Field Data Collection

Speed and placement data were collected on each of the nine curves for both lanes at the estimated PC and at the midpoint. The placement data were taken with contact strips connected to electronic recorders. The spot speeds were taken with radar speed meters. In all cases the vehicle lateral placement of the left front tire was recorded. Both speeds and placements were taken for only free-flowing passenger cars, which for these purposes was defined as one that did not follow another vehicle going in the same direction by less than 5 sec or encounter an oncoming vehicle within 5 sec before or 5 sec after crossing the spot where either the speed or the placement was taken. Only nighttime data were collected and only on weekday nights (Monday through Thursday) under fair weather conditions when the roadway was dry and visibility was not hindered by either mist or fog. An attempt was made to obtain the speed of each vehicle at both the PC and the midpoint of the curve. A similar procedure was followed for collection of the lateral placement data. This was done to reduce the effect of driver and vehicle factors that tend to vary with time or with driver populations. Through this method only the pure effect of the particular curve on a given vehicle was obtained. The total sample consisted of more than 12,000 speed and lateral placement observations.

RESEARCH RESULTS

A multiple regression analysis was performed on the data, yielding the following results for the outside lane:

$$A = -21.87 + \underset{(5.79)}{23.26}\,\text{PVR} + \underset{(0.016)}{0.027}D \qquad \text{(Q-8)}$$

$$R^2 = 0.79 \qquad F = 11.15$$

in which

A = accidents per million vehicle-miles;
PVR = placement variance ratio = $\dfrac{\text{variance of placement at midpoint}}{\text{variance of placement at PC}}$;
D = average deceleration rate = $\dfrac{(\bar{S}_{PC} - \bar{S}_M)(\bar{S}_{PC})}{L}$;
$\bar{S}_{PC}$ = average speed at PC, in miles per hour;
$\bar{S}_M$ = average speed at midpoint, in miles per hour;
L = distance from PC to midpoint, in miles;
R^2 = coefficient of determination; and
F = calculated F-value.

The numbers in parentheses below the regression coefficients are the relevant standard errors. The statistical estimation indicates that 79 percent of the variation in accident rate is explained by the given set of variables. The regression is significant at the 1 percent level according to the F-test. A two-tailed t-test indicates that the coefficient of PVR is significant at the 1 percent level. The simple correlation coefficient of A and PVR is 0.83, whereas this statistic for A and D is 0.45.

The total number of accidents per million vehicle-miles was used as the dependent variable instead of the total number of accidents per million vehicle-miles attributed to vehicles negotiating the outside lane. This was done because it was impossible to ascertain from the accident histories of the curves in which lane the involved vehicle was traveling. If it is assumed that most of the accidents that occur on horizontal curves involve vehicles negotiating the outside lane, the use of the total accident rate rather than an arbitrary assignment of accidents to vehicles negotiating the outside lane would result in more realistic conclusions.

The accident rates for each curve were then modified to eliminate accidents in which the causation factors indicated that the accident was not directly related to negotiating the curve. Examples of such accidents are hitting animals and skidding due to ice and snow. This result should be viewed with caution, however; it was sometimes arbitrary as to whether a particular accident resulted from the vehicle negotiating the curve or from other influencing factors. The result of the multiple regression analysis performed on the data for the outside lane is as follows:

$$A = -17.24 + \underset{(4.96)}{19.59}\,\text{PVR} + \underset{(0.014)}{0.026}D \qquad \text{(Q-9)}$$

$$R^2 = 0.79 \qquad F = 11.04$$

in which all variables are defined as previously. Again, 79 percent of the variation in accident rate is explained by the variation in the foregoing set of variables. The regression is significant at the 1 percent level according to the F-test and a two-tailed t-test indicates that the coefficient of PVR is significant at the 1 percent level. There is little difference between the results obtained in this analysis and the results obtained when the total accident rate was used. The coefficients are slightly smaller because the accident rates were slightly reduced due to the elimination of noncurve-related accidents.

A multiple regression analysis on the data for the inside lane yielded the following results:

$$A = 10.35 + \underset{(13.98)}{16.84}\text{PVR} + \underset{(0.015)}{0.008}D \qquad \text{(Q-10)}$$

$$R^2 = 0.28 \qquad F = 1.175$$

The statistical analysis indicates that 28 percent of the variation in accidents can be explained by the variation in these two variables. However, two-tailed t-tests indicate that neither coefficient is significant at the 5 percent level and the F-test indicates that the regression is not significant at the 5 percent level. This result was expected, because it is believed that a high proportion of the accidents on horizontal curves are caused by vehicles negotiating the outside lane, and thus use of the total accidents on curves as the dependent variable causes a large error in the results for the inside lane.

Although conclusive results cannot be drawn on such a small sample, the statistical analysis does indicate a fairly strong correlation between accident rates and the variance of lateral placement for the outside lane. Thus, if delineation treatments can be shown to reduce the variance in lateral placement, accident rates probably will be reduced also.

The negative intercept in the results for the outside lane was expected: if deceleration rates are reduced to near zero and the placement variance ratio is reduced to near one, which are conditions that would be expected on tangent sections, the model would predict an accident rate of around 2 per million vehicle-miles. The *Traffic Engineering Handbook* (*385*) reports that the accident rate per million vehicle-miles on two-lane tangent sections is 3.6 for the range of ADT that occurred on the present sample of curves. Thus, the model is consistent and plausable, and it indicates that if traffic operations on horizontal curves can be made to approach those that exist on tangent sections, the accident rates on these curves will approach those on tangents.

There has been some discussion in the literature concerning other intermediate criteria that may correlate with accident rates on horizontal curves. Speed change units, mean speeds, variance of speeds, and the skewness of the speed distribution are mentioned. There has been little or no work done on the statistical validation of these criteria; they are often based on the intuition of the researcher. Several tests were made to determine whether any of these criteria are related to accident rates on horizontal curves.

A simple regression was run on speed changes for the outside lane and accidents per million vehicle-miles. The results are:

$$A = 32.15 + \underset{(2.98)}{0.23}\Delta S \qquad \text{(Q-11)}$$

$$r^2 = 0.0008 \quad F = 0.006$$

in which:

$$\Delta S = \bar{S}_{PC} - \bar{S}_M \qquad \text{(Q-12)}$$

Neither the two-tailed t-test nor the F-test indicated statistically significant results. The simple correlation coefficient between A and ΔS of 0.03 indicates that little or no correlation exists between speed change units and accident rates for the outside lane, so that for horizontal curves, at least, reductions in this variable have little or nothing to do with reductions in accident rates.

The speed change unit was regressed against accidents for the inside lane and yielded slightly better results:

$$A = 22.37 + \underset{(1.39)}{2.12}\Delta S \qquad \text{(Q-13)}$$

$$r^2 = 0.25 \quad F = 2.33$$

Neither the two-tailed t-test nor the F-test indicated significance at the 5 percent level. The simple correlation coefficient between A and ΔS in this case is 0.50.

There has been some discussion in the literature concerning use of the skewness of the speed distribution as an intermediate criterion at various locations. It is argued that the more skewed a distribution is, either to the right or to the left, the more hazardous a given location is. Some statistical validation of this measure has been done by Taylor (*386*), who studied the skewness of the speed distributions of sections of a rural highway. To test the hypothesis that the more skewed the distribution of speeds the greater the accident rate, the absolute value of the skewness of the speed distribution at the midpoint of horizontal curves was regressed against accident rates. The results for the outside lane are:

$$A = 28.27 + \underset{(86.36)}{42.55}\text{SKEW} \qquad \text{(Q-14)}$$

$$r^2 = 0.03 \quad F = 0.24$$

in which SKEW is the skewness of speed distribution at the midpoint. The two-tailed t-test and the F-test again indicate no statistical significance at the 5 percent level. The simple correlation coefficient of the skewness of the speed distribution at the midpoint and accident rates is 0.18. The results for the inside lane are:

$$A = 27.57 + \underset{(132.92)}{43.61}\mathrm{SKEW} \qquad \text{(Q-15)}$$

$$r^2 = 0.01 \quad F = 0.11$$

Again, both the two-tailed t- and F-tests indicate no statistical significance at the 5 percent level. The simple correlation coefficient of skewness of the speed distribution at the midpoint of the inside lane and accident rates is 0.12. The results for the inside and outside lanes do not support the hypothesis that the skewness of the speed distribution and accident rates are related on rural horizontal curves.

Another intermediate criterion that is derived from the speed distribution that has been given some credibility recently is the variance in speed. Some researchers maintain that if the variance in speed can be reduced at a given location, accident rates will also be reduced. These researchers implicitly assume that some correlation exists between variance in speed and accident rates, and that high-accident locations should reflect a higher variance in speed than low-accident locations. Thus, the variances in speeds at the PC and midpoint of both lanes were regressed against accident rates and yielded the following results:

$$A = 39.69 - \underset{(0.70)}{0.28}V_{\mathrm{OM}} \qquad \text{(Q-16)}$$

$$r^2 = 0.02 \quad F = 0.16$$

$$A = 46.70 - \underset{(0.76)}{0.47}_{\mathrm{OPC}} \qquad \text{(Q-17)}$$

$$r^2 = 0.05 \quad F = 0.37$$

$$A = 37.32 - \underset{(0.60)}{0.17}V_{\mathrm{IM}} \qquad \text{(Q-18)}$$

$$r^2 = 0.01 \quad F = 0.08$$

$$A = 42.86 - \underset{(0.73)}{0.33}V_{\mathrm{IPC}} \qquad \text{(Q-19)}$$

$$r^2 = 0.03 \quad F = 0.20$$

in which:

V_{OM} = variance of speed, outside lane, midpoint;
V_{OPC} = variance of speed, outside lane, PC;
V_{IM} = variance of speed, inside lane, midpoint; and
V_{IPC} = variance of speed, inside lane, PC.

The two-tailed t-test indicates that none of these variables is significant at the 5 percent level. In addition, the F-test indicates that none of the regressions is significant at the 5 percent level. The simple correlation coefficients of accidents per million vehicle-miles and the foregoing variables are: $r(A, V_{\mathrm{OM}}) = -0.15$; $r(A, V_{\mathrm{OPC}}) = -0.22$; $r(A, V_{\mathrm{IM}}) = -0.10$; $r(A, V_{\mathrm{IPC}}) = -0.17$. Even though the regression coefficients were not significant, it is interesting to note that in all cases these coefficients and the correlation coefficients resulted in negative values. Thus, the signs of the regression coefficients and the correlation coefficients tend to contradict the theory: as the variance in speed increases, accident rates decrease.

It is also maintained by some researchers that if mean speeds are reduced, accident rates will also be reduced at a given location. This hypothesis implicitly assumes that there is some correlation between accident rates and mean speeds, and that high mean speeds indicate high hazard. It is assumed that if a given treatment can reduce mean speeds, this treatment will also reduce accident rates. A statistical analysis on the mean speeds at horizontal curves yielded the following results:

$$A = 97.76 - \underset{(0.86)}{1.89}\bar{S}_{\mathrm{OM}} \qquad \text{(Q-20)}$$

$$r^2 = 0.41 \quad F = 4.79$$

$$A = 135.47 - \underset{(0.89)}{2.70}\bar{S}_{\mathrm{OPC}} \qquad \text{(Q-21)}$$

$$r^2 = 0.57 \quad F = 9.27$$

$$A = 96.36 - \underset{(0.85)}{1.93}\bar{S}_{\mathrm{IM}} \qquad \text{(Q-22)}$$

$$r^2 = 0.42 \quad F = 5.12$$

$$A = 143.50 - \underset{(1.70)}{2.92}\bar{S}_{\mathrm{IPC}} \qquad \text{(Q-23)}$$

$$r^2 = 0.30 \quad F = 2.94$$

in which:

$\bar{S}_{\mathrm{OM}}$ = mean speed, outside lane, midpoint;
$\bar{S}_{\mathrm{OPC}}$ = mean speed, outside lane, PC;
$\bar{S}_{\mathrm{IM}}$ = mean speed, inside lane, midpoint; and
$\bar{S}_{\mathrm{IPC}}$ = mean speed, inside lane, PC.

A two-tailed t-test indicates that only the coefficient of $\bar{S}_{\mathrm{OPC}}$ is significant at the 5 percent level. The F-test indicates that only the regression of A and $\bar{S}_{\mathrm{OPC}}$ is significant at the 5 percent level. The simple correlation coefficients between accident rates and mean speeds are: $r(A, \bar{S}_{\mathrm{OM}}) = -0.64$; $r(A, \bar{S}_{\mathrm{OPC}}) = -0.75$; $r(A, \bar{S}_{\mathrm{IM}}) = -0.65$; $r(A, \bar{S}_{\mathrm{IPC}}) = -0.54$. The results indicate that although some correlation does exist between accident rates and mean speeds, the negative coefficients may reasonably be interpreted to mean that motorists recognize the characteristics that create more or less hazardous horizontal curves and reduce their speeds only on those curves that are more hazardous. This does not in any way support the theory expounded by some researchers that if treatments can reduce mean speeds they will also reduce accident rates.

CONCLUSIONS

Although firm conclusions cannot be drawn on the small sample of nine sites that was used in this study, the statistical analysis does indicate the following:

1. A fairly strong correlation between accident rates and the variance of lateral placement on horizontal curves

seems to exist. Thus, if delineation treatments can be shown to reduce the variance in lateral placement, accident rates probably will also be reduced. For example, it is shown in Appendix N that raised pavement markers and painted edge lines and center lines reduce the variance in lateral placement. Thus, it can be expected that if either of these two treatments is used on horizontal curves, accident rates on these curves probably will also be reduced.

2. Although strong evidence does not exist in support of the hypothesis that accident rates are correlated with deceleration rates on horizontal curves, there seems to be some justification in concluding that this correlation may also exist. It would seem that delineation treatments that reduce this statistic are ones that provide advance warning of curves. These include raised pavement markers and post delineators. In addition, lowering speed limits may also affect this statistic.

3. There seems to be little or no evidence to support the conclusion that changes in speed from entry into the curve to the midpoint are correlated with accident rates on horizontal curves.

4. This analysis does not support the hypothesis that the skewness of the speed distribution is a valid intermediate criterion on horizontal curves.

5. The present analysis indicates that there is little or no correlation between accident rates and the variance in speed distributions on horizontal curves. This does not support the conclusion that reductions in the variance of speed will result in reductions in accident rates and, in fact, a tendency toward negative correlations was found.

6. Although fairly good correlations between accident rates and mean speeds on horizontal curves were obtained, the regression and correlation coefficients were negative, which does not in any way support the hypothesis that reductions in mean speeds will result in reductions in accident rates on horizontal curves.

SUGGESTIONS FOR FUTURE RESEARCH

Although time and money constraints kept the sample size small in this study, the results indicate that some correlation does in fact exist between accident rates and intermediate criteria. Additional research with much larger samples on horizontal curves and other traffic situations probably will lead to results with practical significance. If larger samples are used, the functional relationship between accident rates and intermediate criteria can be obtained with greater confidence. Knowledge of these relationships would permit the highway engineer to evaluate delineation treatments, and a wide variety of highway improvements, quickly and efficiently.

APPENDIX R

PROBLEM ANALYSIS GUIDELINE FORMS *

The Problem Analysis Guideline Form is a tool by which the traffic engineer can systematically tie together accidents, driver/vehicle movements, information requirements, and information deficiencies, all within the context of specific roadway situations. It is so designed as to require consideration of factors other than simple visibility of the system/treatment. These include the timing of the information, clarity of meaning, and the speed with which the meaning can be discerned. It focuses on the influences of the delineation system/treatment itself and excludes factors unrelated to delineation, such as driver intoxication, malfunctioning vehicles, etc.

The design of the guideline form was governed by the needs of the traffic engineer for guidelines to upgrade delineation in a class of highway situations (e.g., stop approaches, horizontal curves) or to provide remedial treatment for a specific situation (e.g., high-accident location). It is expected that use of the guideline form will reduce the time required to analyze specific situations in the field, will direct attention to the pertinent factors and will, with widespread use, contribute to increased standardization of analysis and treatment of problem situations.

DEVELOPMENT OF THE GUIDELINE FORMS

The guideline form (see Fig. R-6 for an example of a completely developed working Form) is the result of a rational analysis based on considerations drawn from current practices, observations, consultations, the state-of-the-art summary, and the situation models reported in Appendix A. Development of the guideline form for the horizontal curve situation is described in detail in the following. The working forms for the other "classical" situations (Figs. R-7 through R-12) were derived in a similar manner.

The first step in the development involved listing the types of accidents that might occur at the specific situation under study (Fig. R-1). The accident typology employed is representative of that used by states in their reporting

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forms. The next step consisted of listing the logical antecedents to the accidents, designating them "Prior Movements"; these are also indicated in Figure R-1. Next, the "Information Requirements" for the proper performance of the maneuver called for were listed. Absence of one or more of these information requirements could lead to the prior movements, and thence result in the accident type listed at the left edge of the form. The absence could be physical (i.e., not provided) or perceptual (i.e., not seen).

Instructions for use of the guideline forms, once they have been developed to the stage represented by Figure R-6, are given in Chapter Two. In the following, the procedures employed in developing the form for the horizontal curve situation are described so that the user will be aware of the strength and limitations of the working forms, and so that the procedures may be used by others to develop new forms for other less-common situations of particular interest to them. The specific procedural steps are:

1. Fill in the appropriate accident types, prior movements, and information requirements. Development of these listings is described in the preceding paragraphs.

2. Considering each accident type individually, estimate the relative likelihood of the various prior movements. The prior movement considered most likely to have preceded the accident is rated 10; the other prior movements are then rated relative to that one (see Fig. R-2). Note that the prior movements must be considered in order when the ratings are estimated. For example, in the case of head-on accidents, the center line encroachment prior movement should be rated on the basis of those encroachments not caused by high-speed entry. (Assume normal entry speed; then, how many times is the center line encroachment likely to be the causative factor, in relation to the number of times a high-speed entry is the causative factor?)

3. Estimate the relative importance of the various information requirements in deterring the prior movements. In a sense, the likelihood that the lack of the various information requirements led to the undesirable prior movement is being estimated. This process must be carried out for each prior movement with a rating number for one of the accident types. In Figure R-3 letters A through F have been entered above the prior movements to facilitate understanding of the rating technique. Note that prior movements A and B have been designated as pertinent to head-on accidents. Hence, ratings of the information requirements for these two prior movements are shown in the cells under "Information Requirements" and horizontally across from "Head-On Accidents." Again, the most likely deficient information requirement is rated 10 and the others are rated relative to that one. The ratings for each prior movement (capital letter) are then summed in the right-most column—e.g., 18 for A, "High-Speed Entry."

4. Normalize each of the capital letter ratings to a total of 10. For example, for A each of the ratings is scaled down proportionately from a total of 18 to 10. If this normalization were not carried out, a type B prior movement would carry 35/18 times as much weight as a type A in the later computations. The normalized ratings are shown in Figure R-4.

5. To obtain a measure of the relative importance of each of the deficiencies in information requirements for each type of accident, multiply the normalized ratings in Figure R-4 by the ratings shown under the prior movements for the same accident type. For example, the rating number, 63, shown under "Advance Warning of Curve" for the "Head-on Accident" type, is obtained as follows:

$$5.5 \times 10 + 1.4 \times 6 = 55 + 8.4 = 63$$

Sum the rating numbers, which now relate information requirements to accident type (the prior movements do not enter into any subsequent calculations), to the right-most column. Enter the numbers in the upper-left portions of the cells below information requirements; the lower-right portion is reserved for later computations. The results of these computations are shown in Figure R-5.

6. Normalize the ratings shown in Figure R-5, so that each row totals to 100. This is necessary to give equal weight to each accident used in the analysis of the information requirements for the site. If they were not normalized, a single accident of the left-roadway type would carry 190/160 times as much weight as a single head-on accident in determining the information deficiencies. (Use of this form in the analysis of information deficiencies at a site, or a class of sites of similar nature, is described in Chapter Two.)

SITUATION: Horizontal Curve			Prior Movements							Information Requirements							
Accident Type		No.	High-Speed Entry	Center Line Encroachment	Shoulder Encroachment	Premature Acceleration	Rapid Deceleration	Adjacent Lane Encroach. (Multi-Lane)		Advance Warning of Curve	Location of Beginning of Curve	Direction of Curve	Degree of Curvature	Location of Apex	Lateral Position Limits		
Collision with Vehicle – On-Coming	Head-On																
Collision with Vehicle – On-Coming	Side-Swipe																
Collision with Vehicle – Same Dir.	Rear-End																
Collision with Vehicle – Same Dir.	Side-Swipe																
Left Roadway																	
Sum																	
Normalized Sum																	

Figure R-1. Headings for guideline form, horizontal curve.

SITUATION: Horizontal Curve			Prior Movements							Information Requirements							
Accident Type		No.	High-Speed Entry	Center Line Encroachment	Shoulder Encroachment	Premature Acceleration	Rapid Deceleration	Adjacent Lane Encroach. (Multi-Lane)		Advance Warning of Curve	Location of Beginning of Curve	Direction of Curve	Degree of Curvature	Location of Apex	Lateral Position Limits		
Collision with Vehicle – On-Coming	Head-On		10	6													
Collision with Vehicle – On-Coming	Side-Swipe		8	10		1											
Collision with Vehicle – Same Dir.	Rear-End		10				7	1									
Collision with Vehicle – Same Dir.	Side-Swipe		3				3	10									
Left Roadway			10		8	1											
Sum																	
Normalized Sum																	

Figure R-2. Example of estimation of relative likelihood of prior movements, by accident type, horizontal curve.

SITUATION: Horizontal Curve				Prior Movements							Information Requirements							
				A	B	C	D	E	F									
Accident Type			No.	High-Speed Entry	Center Line Encroachment	Shoulder Encroachment	Premature Acceleration	Rapid Deceleration	Adjacent Lane Encroach. (Multi-Lane)		Advance Warning of Curve	Location of Beginning of Curve	Direction of Curve	Degree of Curvature	Location of Apex	Lateral Position Limits		
Collision with Vehicle	On-Coming	Head-On		10	6						A 10 B 5	A 3 B 4	B 2	A 5 B 10	B 4	B 10		A 18 B 35
Collision with Vehicle	On-Coming	Side-Swipe		8	10		1				A 10 B 5	A 3 B 4	B 2	A 5 B 10 D 5	B 4 D 10	B 10 D 7		A 18 B 35 D 22
Collision with Vehicle	Same Dir.	Rear-End		10				7	1		A 10 E 5 F 2	A 3 E 3 F 3	E 1 F 1	A 5 E 10 F 6	E 2 F 2	E 4 F 10		A 18 E 25 F 24
Collision with Vehicle	Same Dir.	Side-Swipe		3				3	10		A 10 E 5 F 2	A 3 E 3 F 3	E 1 F 1	A 5 E 10 F 6	E 2 F 2	E 4 F 10		A 18 E 25 F 24
Left Roadway				10		8	1				A 10 C 8	A 3		A 5 C 10 D 5	C 2 D 10	C 7 D 7		A 18 C 27 D 22
Sum																		
Normalized Sum																		

Figure R-3. Example of prior movements/information requirements relationships, horizontal curve.

SITUATION: Horizontal Curve				Prior Movements							Information Requirements							
				A	B	C	D	E	F									
Accident Type			No.	High-Speed Entry	Center Line Encroachment	Shoulder Encroachment	Premature Acceleration	Rapid Deceleration	Adjacent Lane Encroach. (Multi-Lane)		Advance Warning of Curve	Location of Beginning of Curve	Direction of Curve	Degree of Curvature	Location of Apex	Lateral Position Limits		
Collision with Vehicle	On-Coming	Head-On		10	6						A5.5 B1.4	A1.7 B1.1	B0.6	A2.8 B2.9	B1.1	B2.9		A 10 B 10
Collision with Vehicle	On-Coming	Side-Swipe		8	10		1				A5.5 B1.4	A1.7 B1.1	B0.6	A2.8 B2.9 D2.3	B1.1 D4.5	B2.9 D3.2		A 10 B 10 D 10
Collision with Vehicle	Same Dir.	Rear-End		10				7	1		A5.5 E2.0 F0.8	A1.7 E1.2 F1.3	E0.4 F0.4	A2.8 E4.0 F2.5	E0.8 F0.8	E1.6 F4.2		A 10 E 10 F 10
Collision with Vehicle	Same Dir.	Side-Swipe		3				3	10		A5.5 E2.0 F0.8	A1.7 E1.2 F1.3	E0.4 F0.4	A2.8 E4.0 F2.5	E0.8 F0.8	E1.6 F4.2		A 10 E 10 F 10
Left Roadway				10		8	1				A5.5 C3.0	A1.7		A2.8 C3.7 D2.3	C0.7 D4.5	C2.6 D3.2		A 10 C 10 D 10
Sum																		
Normalized Sum																		

Figure R-4. Example of normalized ratings for prior movements/information requirements relationships, horizontal curve.

SITUATION: Horizontal Curve			Prior Movements							Information Requirements							
Accident Type		No.	High-Speed Entry	Center Line Encroachment	Shoulder Encroachment	Premature Acceleration	Rapid Deceleration	Adjacent Lane Encroach. (Multi-Lane)		Advance Warning of Curve	Location of Beginning of Curve	Direction of Curve	Degree of Curvature	Location of Apex	Lateral Position Limits		
Collision with Vehicle, On-Coming	Head-On									63	24	4	45	7	17		160
Collision with Vehicle, On-Coming	Side-Swipe									58	25	6	54	15	32		190
Collision with Vehicle, Same Dir.	Rear-End									70	27	3	59	6	15		180
Collision with Vehicle, Same Dir.	Side-Swipe									31	22	5	45	10	47		160
Left Roadway										79	17	0	60	10	24		190
Sum																	
Normalized Sum																	

Figure R-5. Example of contributions of deficiencies in information requirements to accident types, horizontal curve.

SITUATION: Horizontal Curve			Prior Movements							Information Requirements							
Accident Type		No.	High-Speed Entry	Center Line Encroachment	Shoulder Encroachment	Premature Acceleration	Rapid Deceleration	Adjacent Lane Encroach. (Multi-Lane)		Advance Warning of Curve	Location of Beginning of Curve	Direction of Curve	Degree of Curvature	Location of Apex	Lateral Position Limits		
Collision with Vehicle, On-Coming	Head-On									39	15	3	28	4	11		100
Collision with Vehicle, On-Coming	Side-Swipe									31	13	3	28	8	17		100
Collision with Vehicle, Same Dir.	Rear-End									39	15	2	33	3	8		100
Collision with Vehicle, Same Dir.	Side-Swipe									19	14	3	28	6	30		100
Left Roadway										41	9	0	32	5	13		100
Sum																	
Normalized Sum																	

Figure R-6. Example of Guideline Form I, horizontal curve (normalized ratings from Fig. R-5).

SITUATION: No-Passing Zone		Prior Movements							Information Requirements							
Accident Type	No.	Short Pre-Pass Headway	Late Initiation of Pass	Forced Return (Abort)	Forced Return after Passing	Shoulder Encroachment			Advance Warning of No-Passing Zone	Location of Beginning of No-Passing Zone	Location of End of No-Passing Zone	Lateral Position Limits				
Collision with Vehicle — On-Coming — Head-On									48	45	7	0				100
Collision with Vehicle — On-Coming — Side-Swipe									39	42	19	0				100
Collision with Vehicle — Same Dir. — Rear-End									28	36	36	0				100
Collision with Vehicle — Same Dir. — Side-Swipe									28	41	31	0				100
Left Roadway									28	44	14	14				100
Sum																
Normalized Sum																

Figure R-7. Example of Guideline Form I, no-passing zone.

SITUATION: Pavement Width Transition		Prior Movements							Information Requirements							
Accident Type	No.	Median Encroachment	Abrupt Lane Change to Through Lane	Rapid Deceleration in Through Lane	Lane Change into Dropped Lane	Stopping in Dropped Lane	Overtaking Merge from Dropped Lane	Taper Shoulder Encroachment	Advance Warning of Width Transition	Beginning of Taper	Direction of Taper (Left or Right)	Length of Taper				
Collision with Vehicle — On-Coming — Head-On									49	12	25	14				100
Collision with Vehicle — On-Coming — Side-Swipe									49	12	25	14				100
Collision with Vehicle — Same Dir. — Rear-End									26	12	36	26				100
Collision with Vehicle — Same Dir. — Side-Swipe									42	17	17	24				100
Left Roadway									31	16	21	32				100
Sum																
Normalized Sum																

Figure R-8. Example of Guideline Form I, pavement width transition (narrowing).

SITUATION: Ramp Diverge			Prior Movements							Information Requirements							
Accident Type		No.	Speed Reduction (Upstream)	Late Lane Change (Upstream)	Late Entry into Deceleration Lane	High-Speed Ramp Entry	Sudden Deceleration in Mainstream	Gore Encroachment	Sudden Deceleration in Deceleration Lane	Advance Warning Sign	Beginning of Deceleration Ramp	Location of Gore	Ramp Curvature				
Collision with Vehicle	Rear-End									32	18	30	20				100
Collision with Vehicle	Side-Swipe									38	35	23	4				100
Left Roadway	Median									44	39	17	0				100
Left Roadway	Gore									22	27	34	17				100
Left Roadway	Right Edge									37	33	23	7				100

Figure R-9. Example of Guideline Form I, ramp diverge.

SITUATION: Turn (Simple Geometry)				Prior Movements								Information Requirements						
Accident Type			No.	High-Speed Approach	Abrupt Lane Change for Turn	Median Encroachment	Encroachment on Intersecting Road	Turn from the Wrong Lane	Improper Lane Position After Turn			Advance Warning of Intersection	Designation of Proper Turning Maneuvers, by Lane	Lateral Position Limits	Stop Limit	Lane Definition on Intersecting Road		
Collision with Vehicle	On-Coming	Head-On										6	9	35	15	35		100
Collision with Vehicle	On-Coming	Angle										25	13	4	45	13		100
Collision with Vehicle	On-Coming	Side-Swipe										9	9	43	14	25		100
Collision with Vehicle	Same Direction	Rear-End										50	34	5	11	0		100
Collision with Vehicle	Same Direction	Angle										31	45	16	8	0		100
Collision with Vehicle	Same Direction	Side-Swipe										27	45	12	5	11		100
Left Roadway												16	13	6	18	47		100

Figure R-10. Example of Guideline Form I, turn (simple geometry).

SITUATION: Turn (with Storage) — Accident Type			No.	Prior Movements: High-Speed Approach	Multiple Lane Change into Storage Lane	Late Entry into Storage Lane	Median Encroachment	Encroachment on Intersecting Road	Turn from the Wrong Lane	Straight from Turn Lane	Improper Lane Position After Turn	Information Requirements: Advance Warning of Intersection	Beginning of Storage Lane	Lateral Position Limits	Stop Limit	Lane Definition on Intersecting Road		
Collision with Vehicle	On-Coming	Head-On										16	6	35	11	32		100
		Angle										33	5	14	37	11		100
		Side-Swipe										12	7	45	10	26		100
	Same Direction	Rear-End										46	39	6	9	0		100
		Angle										47	14	32	7	0		100
		Side-Swipe										33	37	17	4	9		100
Left Roadway												14	5	6	16	59		100
Sum																		
Normalized Sum																		

Figure R-11. Example of Guideline Form I, turn (with storage).

SITUATION: Stop Approach — Accident Type			No.	Prior Movements: High-Speed Approach	Center Line Encroachment	Adjacent Lane Encroachment	Shoulder Encroachment	Encroachment on Intersecting Road			Information Requirements: Advance Warning of Stop Requirement	Location of Stop Limit	Lateral Position Limits					
Collision with Vehicle	On-Coming	Head-On									27	22	51					100
		Angle									57	43	0					100
		Side-Swipe									30	19	51					100
	Same Dir.	Rear-End									71	29	0					100
		Side-Swipe									23	17	60					100
Left Roadway											27	18	55					100
Sum																		
Normalized Sum																		

Figure R-12. Example of Guideline Form I, stop approach.

APPENDIX S

ACCIDENT ANALYSES *

A logical source of information on the effects of delineation, or the lack of delineation, is the accident records that result from police investigations. Unfortunately, the reports are not definitive as to causative factors, at least to the extent desirable for details on delineation. There are practical limitations to the depth of routine investigations and in the coding of accident reports into a format compatible with computer processing and storage.

In spite of these severe limitations, it is possible to use accident records to obtain estimates that are substantially more concrete and reliable than those from other sources. In-depth accident investigations are desirable for these purposes; but their cost limits the sample size so drastically that the results cannot yet be interpreted as generally applicable to the bulk of accidents.

The first section of this appendix makes use of accident records by considering those high-accident locations reported by all the states in an Accident Priority Program conducted by the Bureau of Public Roads. The implication of delineation in these hazardous locations is discussed.

The second section of this appendix derives a rough estimate of the costs, in terms of casualties and property damage, of accidents that are likely to be related to delineation factors. This is derived from a sample of accident records from the Pennsylvania Department of Transportation, Bureau of Accident Analysis.†

ANALYSIS OF HIGH-ACCIDENT LOCATIONS

The application of delineation treatments ideally will be in response to some identified needs for increased information transfer. One task within this project was to quantify and evaluate the ability of alternative systems to meet these needs. As such, the analysis procedure was oriented to specific locations or to location types capable of being characterized by a set of variables. However, the decision to adopt delineation systems for general application must be based on cost-effectiveness measures as developed in Appendix T. In an attempt to understand better the generalized needs and problem areas, the researchers conducted an analysis of the high-accident locations in the United States.

The use of accident records in research studies has been criticized for the lack of uniformity and precision in reporting procedures. Although these factors cannot be disregarded, the reduction of accidents was the primary objective of this study; and it was believed that these data were adequate to provide some insight into the potential for achieving this objective.

Many studies have been conducted on the relationship between accidents and geometric features (*32, 348*), but these studies were conducted on a site basis rather than a political unit basis. Here the ultimate interest is in the implementation of delineation systems and thus the concern is with the possible use of this tool on a statewide basis. Recognition of the vast differences between the climatological and developmental characteristics of the various states led to concern over the way in which these differences might be reflected in the need for, or application of, delineation. The ready accessibility of the data contributed to the decision to undertake this study to document these differences if they exist.

The data used for this analysis were obtained from the Office of Traffic Operations, Bureau of Public Roads. The data represent the 20 highest accident locations in each of the 48 contiguous states and the District of Columbia, as submitted under the federally sponsored Accident Priority Program. Access to these data was conditioned on the development of an information code that would permit the desired analyses without identifying specific locations or states. The following code system was developed for this purpose, adhering closely to the listing format suggested in an information memo issued by the Bureau of Public Roads.

Coding Form

Column 1—Region

Code 1—Arkansas, North Carolina, Mississippi, Alabama, Georgia, South Carolina, Louisiana, Florida.
Code 2—Tennessee, Kentucky, West Virginia, Virginia, Pennsylvania, Maryland.
Code 3—New Jersey, Delaware, Rhode Island, Connecticut, Massachusetts, District of Columbia.
Code 4—Michigan, Ohio, Indiana, Illinois, Iowa, Missouri.
Code 5—Montana, North Dakota, Minnesota, Wisconsin, South Dakota, Wyoming.
Code 6—Nebraska, Colorado, Kansas.
Code 7—New Mexico, Texas, Oklahoma.
Code 8—Washington, Oregon, Idaho, Nevada, Utah.
Code 9—California, Arizona.
Code 0—Maine, New Hampshire, Vermont, New York.

Column 2—Basis of Data Listing

Code 1—Computer listing of accidents.
Code 8—Other.
Code 9—Not reported.

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† The conclusions and assumptions are those of the writers and are not to be considered as supported or endorsed by the Pennsylvania Department of Transportation.

Column 3—Environmental Classification of Roadway

Code 1—Rural.
Code 2—Urban.

Column 4—Administrative Classification of Roadway

Code 1—Federal-Aid Primary System.
Code 2—Federal-Aid Secondary System.
Code 3—Interstate System.
Code 4—Federal-Aid Urban.
Code 5—State roads.
Code 8—Others.

Column 5—General Location

Code 1—Bridges or culverts.
Code 2—Curves.
Code 3—Intersections.
Code 4—Railroad crossing and railroad at grade.
Code 5—Interchange ramps.
Code 6—Weaving sections.
Code 7—Parking lanes, etc.
Code 8—Others.
Code 9—Not reported.

Column 6—Hazard

Code 1—Sign and signalization.
Code 2—Pavement markings.
Code 3—Guardrails.
Code 4—Other delineation.
Code 5—Geometrics.
Code 6—Capacity.
Code 8—Others.
Code 9—Not reported.

Column 7—Justification

Code 1—Concentration of accidents at the location.
Code 2—Record of accidents at similar locations.
Code 3—Findings of applicable research.
Code 4—Engineering judgment.
Code 8—Others.
Code 9—Not reported.

Column 8—Proposed Improvement

Code 1—Delineation.
Code 2—Geometrics.
Code 8—Others.
Code 9—None.

Column 9—Cost

Code 1—High; projects above $50,000.
Code 2—Medium; projects between $10,000 and $50,000.
Code 3—Low; projects below $10,000.
Code 9—Not reported.

Analyses

The accident data were transferred to a punched card format, and a computer program was written to list each accident location in the appropriate cells of matrix forms (Fig. S-1). That is, accidents within region 1 that occurred at general location type 1 (e.g., bridge or culvert) would be listed in cell 1-1 of Figure S-1. The accident record numbers would also be listed in cells of the hazard/general location table. Each accident location, therefore, is listed at least once in each of these tables. Inasmuch as some accident locations included more than one type of hazard, these locations occur in two or more cells of the hazard/general location tables. The entries in the tables are then summed to give the frequency of occurrence of each type of hazard at all general locations and each general location in all different regions. With the observed frequency distribution, standard Pearson's chi-square tests were conducted to establish the association between type of hazard, general location, and region.

The first chi-square test conducted was a 10 × 5 design containing all ten regional groups versus five location types (curves, intersections, interchange ramps, bridges and culverts, and all other). The remaining categories included in the data format were combined with the "other" category due to the small sample size in many of these cells. The resultant chi-square entries are shown in Figure S-2, assuming no differences in the regions as the null hypothesis.

The results of the test were significant at the 0.05 level, indicating that there are significant regional differences in the type of locations included in accident priority programs throughout the U.S. For example, in regions 2, 5, and 10 there appear to be an inordinately high number of class 2 (curve) locations on the priority list. Conversely, regions 2 and 10 indicate a relatively low number of class 3 locations (intersections). The other regions display varying sets of characteristic high- and low-type locations.

This information alone does not tell enough to determine the probable impact of delineation treatments on problem locations, but does indicate that these differences do occur. Further testing was devised to isolate the topographic, environmental and developmental differences between these regions and to relate these differences to the location types. The remaining tests were then conducted to determine whether these differences could be used in establishing the potential for delineation treatments being tested in this study.

The regions were grouped into classes describing climatological or developmental differences that were believed might be important to determining the applicability of delineation treatments. Because certain treatments are not feasible where they might be covered by snow, the first division was made between snowy and nonsnowy regions. For this analysis, regions 1, 7, and 9 were categorized as nonsnowy and all other regions were considered to be subject to snowfall. Location types 6 and 7 were eliminated because they contained too few entries. Figure S-3 shows the chi-square analysis entries assuming the null hypothesis that each location was distributed in the same proportions regardless of snowfall.

REGION / LOCATION	1.......	n
1	1...1...	2...n...
2	1...2...	2...n...
. . m		m...n...

HAZARD / LOCATION	1.......	n
1	...1...1	
2		
. . m		

Figure S-1. Program output format for chi-square testing.

REGION / LOCATION	1	2	3	4	5	6	7	8	9	10	TOTAL
BRIDGE	49 / 31	16 / 11	2 / 14	21 / 9	10 / 15	5 / 10	11 / 10	1 / 12	3 / 7	8 / 7	126
CURVE	26 / 25	15 / 9	6 / 12	2 / 8	17 / 12	2 / 9	3 / 8	0 / 10	5 / 5	26 / 6	102
INTER-SECTION	60 / 59	12 / 21	37 / 27	10 / 17	28 / 28	17 / 19	15 / 18	39 / 23	13 / 12	7 / 13	238
RAMP	5 / 9	1 / 3*	10 / 4*	9 / 2*	5 / 4*	3 / 3*	2 / 3*	1 / 3*	0 / 2*	0 / 2*	36
OTHERS	54 / 70	25 / 25	34 / 32	15 / 21	31 / 32	37 / 23	29 / 21	35 / 28	19 / 14	3 / 16	282
TOTAL	194	69	89	57	91	64	60	76	40	44	784

df = 36; $\chi^2_{0.05}$ = 51; χ^2 = 212

*Not included in calculations

OBSERVED / EXPECTED

Figure S-2. Chi-square entries for regions vs general locations.

The results of this analysis indicate that there are statistically significant differences between the type of locations that are particularly hazardous in those areas subject to snow and those not subject to snow. The principal source of this difference is the higher than expected number of bridges and culverts identified as hazardous locations in the nonsnowy regions as opposed to the predominance of interchange ramps in the high-accident location listing in snowy regions. Although this may indicate a difference between single-car leaving-the-road-type accidents and multiple-car accidents in these two regions, it does not provide much information on which to base delineation decisions. It is unlikely that any single test, interpreted in isolation from the others, will provide a true understanding of delineation potential. However, the results of the various analyses, each in the context of the other test, may provide some insights into possible applications.

The analysis of differences between snowy and nonsnowy regions was continued to seek further insight into the potential for different delineation treatments. These regions were tested for the type of hazard identified in the listing. Figure S-4 shows the chi-square entries for this analysis.

This test resulted in the identification of differences between the hazards associated with the two region types. These differences were statistically significant at the 0.05 level using the same null hypothesis as in the previous tests. This can be attributed primarily to the larger than expected number of delineation hazards associated with the snowy regions when compared to the nonsnowy regions.

REGION / LOCATION	SNOWY	NON-SNOWY	TOTAL
BRIDGE OR CULVERT	63 / 78	63 / 48	126
CURVE	68 / 64	34 / 38	102
INTER-SECTION	150 / 149	88 / 89	238
RAILROAD	20 / 19	10 / 11	30
INTERCHANGE RAMP	29 / 23	7 / 13	36
OTHER	159 / 155	90 / 94	249
NOT REPORTED	31 / 32	21 / 20	52
TOTAL	520	313	833

df = 6; $\chi^2_{0.05}$ = 12.6; χ^2 = 12.9

OBSERVED / EXPECTED

Figure S-3. Chi-square entries for snowy and nonsnowy regions vs general locations.

It appears that the effect of improved delineation treatments would be used most widely in those portions of the U.S. that are subject to snowfall. At least, this is the area that identified lack of proper delineation as a primary source of trouble at those locations experiencing a high number of accidents. Further, these locations seem to involve predominantly freeway-associated geometrics.

A similar set of analyses was conducted on regions identified as mountainous and nonmountainous. These results (Fig. S-5 and S-6) indicate that the type of location differs significantly, with a higher than expected number of curves showing up as hazardous locations in mountainous areas and a lower than expected number of bridges and culverts being identified in these areas. However, the analysis of hazard type versus region indicates no significant difference (0.05 level) in the type of hazard associated with each region.

Thus, the fairly obvious association of high-accident locations with curves in the mountainous area is identified; but the analysis failed to identify any meaningful stratification of the potential for delineation treatments.

REGION / HAZARD	SNOWY	NON-SNOWY	TOTAL
GEOMETRICS & CAPACITY	216 / 226	120 / 110	336
PVT. MARKING AND DELIN.	127 / 104	28 / 51	155
GUARDRAILS & OTHERS	14 / 19	14 / 9	28
SIGNS AND SIGNALIZATION	83 / 92	54 / 45	137
TOTAL	440	216	656

df = 3; $\chi^2_{0.05}$ = 7.81; χ^2 = 23.6

OBSERVED / EXPECTED

Figure S-4. Chi-square entries for snowy and nonsnowy regions vs hazard type.

REGION / LOCATION	MOUNTAINOUS	NON-MOUNTAINOUS	TOTAL
BRIDGE OR CULVERT	38 / 52	88 / 74	126
CURVE	63 / 42	39 / 60	102
INTER-SECTION	99 / 98	139 / 140	238
RAILROAD	9 / 12	21 / 18	30
INTERCHANGE RAMP	7 / 15	29 / 21	36
OTHER	103 / 103	146 / 146	249
NOT REPORTED	24 / 21	28 / 31	52
TOTAL	343	490	833

df = 6; $\chi^2_{0.05}$ = 12.6; χ^2 = 33.5 — OBSERVED / EXPECTED

Figure S-5. Chi-square entries for mountainous and nonmountainous regions vs general locations.

LOCATION / HAZARD	MOUNTAINOUS	NON-MOUNTAINOUS	TOTAL
GEOMETRICS AND CAPACITY	100 / 103	196 / 193	296
PVT. MARKING AND DELIN.	50 / 48	88 / 90	138
GUARDRAILS AND OTHERS	4 / 9	22 / 17	26
SIGNS AND SIGNALIZATION	47 / 41	70 / 76	117
TOTAL	201	376	577

df = 3; $\chi^2_{0.05}$ = 7.81; χ^2 = 5.8 — OBSERVED / EXPECTED

Figure S-6. Chi-square entries for mountainous and nonmountainous regions vs hazard type.

REGION / LOCATION	URBANIZED	NON-URBANIZED	TOTAL
BRIDGE OR CULVERT	34 / 39	75 / 70	109
CURVE	39 / 31	48 / 56	87
INTER-SECTION	67 / 68	120 / 119	187
RAILROAD	6 / 10	23 / 19	29
INTERCHANGE RAMP	19 / 12	15 / 22	34
OTHER	63 / 68	127 / 122	190
TOTAL	228	408	636

df = 5; $\chi^2_{0.05}$ = 11.1; χ^2 = 13.6 — OBSERVED / EXPECTED

Figure S-7. Chi-square entries for urbanized and nonurbanized regions vs general locations.

A third aggregation of regions was made by separating those states with a high level of urbanization from those with predominantly rural character. A similar analysis was conducted as shown in Figure S-7. Once again, it was the large number of freeway ramp locations identified as high-accident locations in urbanized areas that contributed most to the significant differences.

Because the level of urbanization should be correlated with the ratio of intersections to other geometric features, and because a test had already been conducted indicating that delineation (or lack of it) was a predominant hazard at ramp locations, it was decided to test intersection and nonintersection locations versus hazard type. Figure S-8 shows the entries in this chi-square analysis for the same null hypothesis as used in the other tests. These differences are significant (0.05 level), with each type of hazard contributing to this difference. The point of interest in selecting potential delineation applications is the predominance of delineation being mentioned as a hazard in intersection-type locations versus geometrics mentioned for nonintersection locations.

The final test conducted was for general locations versus hazards for the aggregation of all regions. This type of analysis indicates which situations present the best prospects for implementing the results of this project on a nationwide basis. Because several situations have been defined for special study in this project, it seems important to determine the predominant hazards that are associated with situations identified as having experienced a large number of accidents.

The entries in the chi-square matrix shown in Figure S-9 indicate that the lack of "pavement marking and delineation" is mentioned as a hazard more often than would be expected for the intersection locations. Hence, it appears that highway engineers believe more attention should be directed toward the proper marking of intersections.

LOCATION / HAZARD	INTERSECTION	NON-INTERSECTION	TOTAL
GEOMETRICS AND CAPACITY	112 / 159	180 / 133	292
PVT. MARKING AND DELIN.	99 / 74	37 / 62	136
GUARDRAILS AND OTHERS	4 / 14	21 / 11	25
SIGNS AND SIGNALIZATION	96 / 64	21 / 53	117
TOTAL	311	259	570

df = 3; $\chi^2_{0.05}$ = 7.81; χ^2 = 100.5 — OBSERVED / EXPECTED

Figure S-8. Chi-square entries for intersection and nonintersection locations vs hazard type.

HAZARD / LOCATION	GEOM. AND CAPACITY	PVT.MARKING AND DELIN.	GUARDRAIL AND OTHER	SIGNS AND SIGNAL.	TOTAL
CURVE	69 / 39	17 / 26	11 / 15	10 / 27	107
INTER-SECTION	43 / 90	77 / 60	27 / 35	100 / 62	247
RAMP	123 / 91	57 / 62	37 / 36	35 / 63	252
OTHER	7 / 22	12 / 15	20 / 9	21 / 14	60
TOTAL	242	163	95	166	666

df = 9; $\chi^2_{0.05}$ = 16.9; χ^2 = 114.3 — OBSERVED / EXPECTED

Figure S-9. Chi-square entries for four subgroups of hazards vs all general locations.

Delineation does not appear to be a major factor in the curve accident locations. This finding, however, may be due to the inordinately high ranking of geometrics and capacity as the hazard at curves; i.e., engineers appear to believe that inadequacies in geometry are the major cause of the problem and do not blame inadequate delineation for the safety problem. Further, it is particularly interesting to note that it is not the lack of treatment with signs or signalization that is identified as the hazard at the curve locations, though it is important at intersections.

One fault of chi-square analysis is that it lends itself to many interpretations, as it does not identify cause-effect relationships, or even correlations between variables. Instead, it merely indicates whether the proportion of events observed is different from what would be expected under a random process and leaves the interpretation to the analyst. Conclusions other than those mentioned in the previous paragraphs are possible by other analysts reviewing the same data.

COSTS OF ACCIDENTS RELATED TO DELINEATION

Accident reports attempt to provide data for a wide variety of purposes. Because of the limitations in time for investigation, in detail of coding categories, and in interpretation during encoding, transferring, and decoding, the information is often incomplete or limited for satisfying any one specific requirement for data. Causative factors are routinely reported, but they are often extremely subjective in nature. The accident records provide room for one, two, or three causation factors in any accident, with 94 coded factors the analyst can cite in addition to "other." There is no provision for elaboration of these other factors.

Pennsylvania began in 1966 to gather accident reports from municipalities in a systematic supplementation of reports from the State Police. More than 90 percent of the municipalities now participate in this program, resulting in 254,450 reported accidents in 1966. This grew to 292,192 for the year 1969, the most recent compilation available. In 1969, the reported casualties totaled 95,497 persons, including 2,080 killed and 93,417 injured; there were 196,695 accidents that involved property damage only. Based on the estimate derived from the sample, the property damage exceeded $294,500,000 from reported accidents in 1969. This does not include the damage reported as unknown (approximately 4 percent), the accidents that were not reported, or those that resulted in less than $100 damage (for which reports are not required).

Computerized accident records are essential for handling large numbers of detailed reports. Routine summaries and compilations, once the programming has been established, can be produced quickly and inexpensively. However, compilations for special purposes require programming and elimination of errors, an expensive and time-consuming process. In the present task, the problem was compounded by the fact that the Pennsylvania accident records are processed on a Burroughs computer, whereas the University uses an IBM 360/67 computer that has a different format for magnetic tape encoding. Sufficient computer processing time was not available at the records bureau, so a translation was required before the records could be read by the University's facility. This further limited the scope of this analysis.

The accident records are used to produce several routine statistical reports, such as type of object hit; age and sex of drivers or other persons involved; hour, day, month, and weather conditions; and vehicle types, location, and direction of movement. From these it is possible to determine the proportions of accidents that occur during darkness or in light, or the proportions that occur on wet or dry roads. It is not possible to derive the proportion of accidents that involve contingent conditions, such as daytime *and* wet, or nighttime *and* rural. Separate programs are required for this determination of one or more contingent conditions, because each individual record must be examined for all contingent conditions.

Delineation (excluding informational signing) can usually be assumed to be relatively unimportant during clear weather with good lighting because of the wealth of other cues to the course of the roadway system. In urban areas (such as on municipal streets or on turnpikes) the traffic density changes the nature of delineation needs. It seems appropriate to expect delineation to be most crucial on state and county roads that are not municipal streets.

The sample obtained for this analysis consisted of approximately 5 percent of the total accident file for 1969. This was a sample of 14,612 cases from a total of 292,192 recorded. Of the sample, 11,846 were eliminated because of urban or turnpike locations, leaving 2,766 cases that occurred on state or county roads outside of municipalities (contingency level 1). Of the rural accidents, 1,083 occurred in daylight with clear weather. This reduced the sample to 1,683 cases that were at the same time rural and happened either at nighttime or during fog, rain, snow, or sleet in the daytime (contingency level 2).

The accident type was used as a further contingency to eliminate accidents involving rear-end collisions, backing or pedestrian accidents, and "other" or "unknown" types, which have no logical implication for delineation. This reduced the contingent sample to 1,293 cases (contingency level 3). The type of accident in this sample is thus restricted to head-on, angle, sideswipe, hitting fixed object, or noncollision (run off road).

The final category used to reduce the total accident sample to those likely to be related to delineation was the reported causation factor 1. Each accident report contains one, two, or three causation factors. This resulted in a total of 397,957 factors for the 292,192 reported accidents during 1969, or only 1.36 each on the average. It was necessary to disregard the second and third factors in the screening process, but this was not likely to affect the conclusions seriously.

Causation factor 1 may be any one of 93 coded factors. Based on the cases at contingency level 4, 30 factors were listed with a frequency of 0. Thus, these factors (Table S-1) need not be considered. The remaining factors were judged to be related to delineation or not to be related. Of the 24 related factors, delineation was judged to be "probable" in the causation of six, leaving 18 factors whose relationship to delineation was judged to be "possible."

One factor was further contingent upon vehicle movement. That factor (code 04) was "exceeding safe speed for traffic or road conditions." The reports had already been screened to rule out dense traffic. It was believed that delineation is of relatively little concern in accidents that occur on straight sections of roadway. Thus, where "exceeding safe speed" was cited, it was included when the offending vehicle was described other than as "moving straight ahead." Movement is described in 93 codings, but "moving straight ahead" (code 01) occurs in approximately 40 percent of all reports.

The "probable" portion thus sets a lower limit to the casualties and property damage that can be attributed to delineation problems. A larger estimate will result from the "probable" plus the "possible" factors and may serve as a rough upper limit to the portion of accidents that might be reduced or eliminated by delineation treatments. (Table S-2 gives those items that were considered not to be related to delineation, and Table S-3 gives the record screening processes.) Table S-4 gives the factors judged to be "probable," the number of accidents in which each was cited, and the casualties and the reported property damage that resulted. Table S-5 gives the factors judged to be "possible."

One obvious deficiency in many reporting systems is the disproportionate use of a few coding categories. For example, in describing locations of accidents, "tangent section, gradient unknown" is cited in 31 percent of all cases and "normal two-street intersection" in 36 percent, leaving 33 percent for the remaining 29 descriptions; 4 of the 95 accident causation factors listed constitute 30 percent of the total; and the offending vehicle is "moving straight ahead" in 40 percent, and "continuing straight through an intersection" in 15 percent, leaving 45 percent distributed among 91 other types of movement listed. In each case more descriptive information is desirable and possible without more computer storage. To maximize the amount of information stored in records where storage is at a pre-

TABLE S-1

CAUSATION FACTORS LISTED IN CODING MANUAL BUT NOT CITED IN ANY CASES OF THE 5 PERCENT ACCIDENT RECORD SAMPLE

CODE	CAUSATION FACTOR	CODE	CAUSATION FACTOR	CODE	CAUSATION FACTOR
03	Driving too slowly	46	Failed to yield right-of-way to pedestrians	70	One or both headlights off
05	Driving in two lanes	52	Poor eyesight, or no glasses	76	Oily or greasy surface
09	Passing in no-passing zone	53	Physical disability	77	Poor or no surface traffic markings
21	Falure to heed pedestrian on roadway	55	Other driver condition	78	Train tracks
25	Fastening seat belt	56	Defective windshield wipers	85	Vehicle wheels caught island, curb, etc.
26	Playing radio	59	Splashed or dirty windshield	88	Narrow roadway
29	Adjusting windows	60	Sunlight glare	95	(Not used)
30	Adjusting other controls	62	Roadside distraction	96	(Not used)
34	Jumping amber light	64	Parked or stopped car in line of vision	97	(Not used)
37	Right turn without signaling	65	Trucks traveling ahead	98	(Not used)

TABLE S-2

CAUSATION FACTORS CITED IN ACCIDENT REPORTS BUT JUDGED NOT TO BE RELATED TO DELINEATION

CODE	CAUSATION FACTOR	CODE	CAUSATION FACTOR	CODE	CAUSATION FACTOR
01	Speeding	38	Left turn without signaling	73	Broken, cracked or bumpy pavement
02	Following with too small headway	40	Switched lane while turning	74	Slippery surface
08	Careless passing	44	Turning without proper clearance	75	Sandy surface
10	Passing on right	45	Proceeding through without clearance	79	Lane width narrowed by snow, debris, etc.
15	Illegal or careless U-turn	47	Illegally stopped on roadway	81	By pedestrian
17	Turn off road with improper or no signal	48	Illegally parked	82	By driver or passenger leaving vehicle
18	Illegal or careless backing up	49	Carless parking maneuver	83	Bicyclist
20	Failure to obey signs or signals	50	Drowsiness, asleep	84	Other things
22	Failure to heed stopped vehicle on roadway	51	Under effects of alcohol, drunk	86	Any causes other than those listed
27	Lighting cigarette	54	Illness, stroke, heart attack, etc.	90	Animal
28	Conversation	57	Defective defrosting system	93	Wind
31	Other tasks by driver	61	Headlight glare	94	Drugs
32	General inattention to conditions	67	Tire blowout	99	Cause unknown
35	Passing red light	68	Brakes failed		
36	Starting on green phase without clearance	69	Steering failed		
		71	One or both taillights off		
		72	Other		

TABLE S-3

REPORT SCREENING PROCESS FOR SELECTING THOSE ACCIDENTS RELATED TO DELINEATION PROBLEMS

CONTINGENCY	CRITERION	REPORTS (NO.)	REPORTS (%)
0	5% sample of all 1969 Pa. accident records	14,612	100
1	Location was state or county road, not in a municipality	2,766	19
2	At night or in daytime with fog, rain, snow, or sleet	1,683	11.5
3	Head-on, sideswipe, angle, hitting fixed object, or non-collision types	1,293	8.8
4	One of 24 codes judged to be related to delineation was listed as causation factor 1.	651	4.5
4A	Of these, 6 codes were judged to indicate delineation as a "probable" causation	164	1.1

TABLE S-4

CAUSATION FACTORS CITED IN ACCIDENT REPORTS WHERE DELINEATION WAS JUDGED TO BE A "PROBABLE" FACTOR

CODE	CAUSATION FACTOR	NO. OF CASUALTIES	NO. OF ACCIDENTS	PROPERTY DAMAGE	NUMBER REPORTED
07	Crossing median	3	3	$ 2,300	3
33	Passing STOP sign	32	18	23,500	16
43	Turning at too high speed	31	35	32,800	34
58	Low visibility due to weather alone	4	6	3,000	6
80	Shoulder drop-off	13	22	24,500	21
91	Driver lost control	55	80	111,200	76
	Total	138	164	$197,300	156
	Mean	0.841/accident		$ 1,265/accident reporting p.d.	

mium, information theory dictates that the categories must approach equal frequency of use. As much as possible, a report system must strive to analyze high-frequency items into more finely described categories so that no one category is used more than ten (or better, five) times as often as the least-used categories. Where 99 codes are available, it is desirable that no one code be used for more than 5 to 10 percent of the cases. This would require retraining of reporters as well as reallocation of codes, but the practical value of the records would be greatly enhanced.

Table S-6 gives the accidents in which delineation was judged a causation factor in this analysis. If the 5 percent sample is assumed to be representative, the lower estimate is derived by multiplying the "probables" in the sample by 20, yielding 3,280 accidents, approximately 1.1 percent of the state total. Property damage was about $4 million, with 4 percent not reporting damage estimates.

When the figures for the records where delineation factors were either possible or probable are combined, the over-all number of accidents rises to 13,020, or 4.5 percent of all accidents. The estimate of casualties becomes 10,500, or 11.0 percent of the total, confirming the casualty rate of this type of accident of more than twice the average. From the over-all proportion of fatalities to total casualties in Pennsylvania, it is estimated that 229 fatalities resulted. Property damage is almost $14 million, for a relatively high cost of $1,113 per accident where a damage estimate was reported. This higher damage cost also implies that the fatality estimate should be well above average, as it is.

The estimates given in Table S-6 are necessarily crude because of the limitation in interpreting accident records

TABLE S-5

CAUSATION FACTORS CITED IN ACCIDENT REPORTS WHERE DELINEATION WAS JUDGED TO BE A "POSSIBLE" FACTOR

CODE	CAUSATION FACTOR	NO. OF CASUAL-TIES	NO. OF ACCIDENTS	PROPERTY DAMAGE	NUMBER REPORTED
04 [a]	Speed too fast for conditions	216	236	$266,300	227
06	Driving on wrong side, partially or fully	101	137	130,700	131
11	Illegal or careless lane change	12	17	9,100	17
12	Careless merge or entrance to traffic stream	27	55	64,100	54
13	Careless weave	5	5	6,300	5
14	Traveling wrong way on one-way street	2	1	0	0
16	Slowing down too quickly	5	5	5,800	5
19	Sudden stop	0	1	400	1
23	Failure to heed construction	9	2	1,300	2
24	Failure to heed other obstacle on roadway	2	1	2,000	1
39	Illegal turn	0	1	500	1
41	Turn from wrong lane	3	8	3,200	8
42	Turning too sharply	0	6	2,800	6
63	Fixed object in line of vision	0	2	600	2
66	Insufficient sight distance, highway design	0	1	0	0
87	Failed to obey YIELD sign	3	3	1,000	3
89	No advance warning for hazardous condition	0	1	300	1
92	Turning too wide	2	5	3,800	5
	Total	387	487	$498,200	469
	Mean	0.795/accident		$ 1,062/accident reporting p.d.	

[a] Contingent upon vehicle movement. If vehicle was "moving straight ahead," it was not included as delineation-related; all other types of movement were included.

for a highly specific goal. One item (speed too fast for road conditions, excluding those where the vehicle was moving straight ahead) constituted one-third of all the accident causation factors considered. The extent to which delineation can influence such driver behavior is not easily ascertained. However, this analysis has indicated that if delineation can be effective in reducing losses in rural accidents in which visibility is restricted, the results can reach up to 4.5 percent of all accidents, involving 11 percent of all casualties and property damage of $14 million per year in Pennsylvania alone.

The National Safety Council * estimates that Pennsylvania fatalities were 4.3 percent of the national total, although the state has 6.2 percent of the licensed drivers and only 3 percent of the nation's road and street mileage, according to the Automobile Manufacturers Association.†

* *Accident Facts* (1970); data for 1969.
† *Automobile Facts and Figures* (1968); data for 1966.

The NSC * estimate is $277 average property damage for all accidents reported. Of these, 73 percent were urban, where lower damage is expected, and 27 percent were rural. Fatalities were 32 percent urban and 68 percent rural, while total accidents were divided 72 percent and 28 percent, respectively. Thus, the higher-than-average property damage and fatality rates are expected in the rural locations examined in the present estimate. Fatalities are about 2.4 times as likely in rural accidents reported by NSC as the average. This agrees with the present analysis, which indicates 11 percent of the casualties were in 4.5 percent of the accidents, also a 2.4 to 1 ratio. If 11 percent of the national death toll were eliminated, 6,200 of the 1969 fatalities would not have occurred. At a rate of $1,113 property damage per accident, this 4.5 percent of the nation's 15.5 million reported accidents would result in $776 million loss. These are the losses that delineation may have some potential for reducing.

TABLE S-6

SUMMARY OF COST ESTIMATES OF DELINEATION-RELATED ACCIDENTS IN PENNSYLVANIA, 1969, EXTRAPOLATED FROM 5% SAMPLE

ITEM	CASUALTIES				ACCIDENTS		REPORTED DAMAGE ($)	
	KILLED [a]	INJURED	TOTAL	(%) [b]	(NO.)	(%)	TOTAL	PER ACC.
Upper estimate (Table S-13 + Table S-14)	229	10,271	10,500	11.0	13,020	4.5	13,910,000	1,113
Lower estimate (from Table S-13)	60	2,700	2,760	2.9	3,280	1.1	3,946,000	1,265

[a] Taken as the same proportion of reported casualties as found in state totals, which list 2,080 killed, 93,417 injured in the 1969 Traffic Accident Statistical Summary for a total of 95,497 casualties in 292,192 accidents.
[b] Percentage of state total, 1969.

APPENDIX T

TECHNIQUES FOR DELINEATION EVALUATION *

Past research efforts in delineation have fallen into two major categories—(1) studies of the physical characteristics of delineation materials, maintenance, initial and long-term direct costs, visibility under various environmental condtions, etc.; and (2) studies of the effects of various delineation treatments and systems on traffic performance.

Objective studies have largely been limited to the first area. Once the variables to be evaluated are decided upon, hard data can be developed through relatively straightforward techniques. There is some difficulty, however, in transferring these numerical differences in the physical characteristics to value as a delineation treatment. For example, suppose that one type of post delineator is visible at a distance 20 percent greater than another, but that it costs 10 percent more. How does one utilize this knowledge to select the "best" delineator? Thus, even though the comparative studies can be objective, their translation to practice often becomes subjective.

The studies of effects of various delineation treatments and/or systems on traffic performance, with few exceptions, fall into one of the following five categories:

1. Accident records analysis. The correlation of specific delineation treatments and/or systems with accident rates is demonstrated. In general, these analyses take two forms: studies comparing accident rates at specific sites before and after installation of the treatment/system; or comparison of accident rates at large numbers of sites with and without the treatment/system of interest.

2. Erratic maneuvers. Where sufficient numbers of erratic maneuvers (conflicts, near-misses, etc.) occur, this approach can be used. It is similar to the accident records analysis except that erratic maneuvers are counted rather than accidents per se.

3. Traffic performance measures. Intermediate measures (such as spot speeds, lateral placements) are taken of traffic performance and analyzed in the manner outlined for techniques 1 and 2. Changes in the mean, variability, or skewness of the distributions of the performance measures may be used as effectiveness criteria. In some cases it is possible to measure driver performance through the use of laboratory simulators.

4. Diagnostic teams. Test installations or laboratory simulations are viewed and evaluated by teams of experts from pertinent disciplines. In some cases, "best" treatment/systems are selected; in others, a numerical ranking is attempted.

5. Driver surveys. Essentially the same experimental approach is used as in the diagnostic team, but with a large sample of the general driver population performing the evaluation.

As is frequently the case, it was not possible to find or develop a single evaluation technique that would be applicable to all the studies within this project or the multitude of studies that may be desired by other highway engineers and researchers. This appendix was developed through study of the application of various evaluation techniques by other researchers, the researchers' experience in the testing phases of the project, and rational application of the concepts developed through studying visibility, information processing, driver information needs, and the general characteristics of delineation systems. Further, this section documents the researchers' thinking on evaluation

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techniques and the rationale in selecting the experimental methods for the testing phases of this project. It also provides guidelines for the application of the evaluation techniques by practicing engineers for other traffic studies.

EMPHASIS ON SAFETY ASPECTS OF DELINEATION

The evaluation techniques are rank ordered to indicate their desirability as evaluation techniques. This order, however, was established on the basis of evaluation of the safety aspects of delineation—if aesthetics, driver comfort, etc., are the primary factors to be evaluated, the order might well be altered. If these factors are to be evaluated, the original problem definition should reflect these factors. The advantages, limitations, and guidelines for use in evaluation must be likewise modified, but the evaluation methodology will remain basically the same. For example, if increased driver comfort is believed to be the major advantage of some proposed treatment/system, it is likely that the driver survey or diagnostic team approach would be most applicable. It might be desirable to use the intermediate traffic performance criteria, but in this case the intermediate measures should be related to comfort rather than to safety-related performance measures. (One might study fatigue-time relationships, for example.)

It is to be emphasized that the discussion of evaluation techniques in this section is directed toward determination of the effectiveness of alternative treatment/systems in terms of potential accident reduction.

Unfortunately, though it is held to be highly desirable, it is not likely that an all-inclusive formula can be developed that will consider all the aspects of delineation, both from the standpoint of effectiveness and cost considerations. The quality of the inputs to the decision makers can be improved (and will be through application of the material in this report), but ultimately engineers must provide their own weighting for the various unquantifiable factors that are inevitably involved.

APPLICATION OF EVALUATION TECHNIQUES

The practicing engineer can use the material in this appendix as guidelines for designing evaluation studies in delineation or closely related areas. He should be able to select the most appropriate test for his specific problem, avoid the major pitfalls, and assess the probable reliability and value of the experimental results before investment in the experimental program.

The discussion is directed primarily toward studies of delineation treatment/systems at specific spot locations. With some generalization (looseness of rigor), these techniques can be applied to more generalized treatments—e.g., evaluation of a proposed treatment for all stop approaches within a district or state. Further relaxation will provide broad guidelines for the evaluation of general concepts (color coding, positive vs negative delineation, etc.) as applied to statewide delineation systems.

The principal advantages and disadvantages of each of the five previously outlined techniques are summarized, and comments relevant to the implementation of the study techniques and interpretation of the results are provided in the first part of this appendix. The order of presentation indicates their desirability as evaluation techniques when accident reduction is the principal criterion of effectiveness. In general, then, the evaluator (practicing engineer or researcher) should select a technique as high up on the list as possible—i.e., consider the accident records analyses technique first; if the limitations are too severe or the implementation guidelines cannot be adhered to, then consider the erratic maneuver technique; and so on.

The second section of this appendix presents guidelines for the application of those cost-effectiveness methodologies most compatible with each of the evaluative techniques. Procedures for estimating delineation treatment costs under various conditions of data availability are also presented.

ACCIDENT RECORDS ANALYSIS

In the accident records analysis approach, an attempt is made to correlate specific delineation treatments and/or systems with accident rates. Although this approach provides one with the "ultimate" answer (it would be possible to make delineation treatment investment decisions on the basis of benefits from expected accident reductions), the instances in which this approach can be used with any degree of confidence are extremely limited, as is pointed out later.

The normal procedure is to use a before-and-after study. The study periods should be of equal length and avoid bias due to fluctuations in environmental or traffic characteristics.

An alternative to the before-and-after methodology is to use a control section method. The accident record at a section(s) with the treatment under evaluation is compared with the accident history at a section(s) that does not have the recommended treatment. It is important in this situation to ensure that each test section(s) has similar volume, geometry, speed, and traffic composition characteristics.

To overcome the problem of obtaining adequate accident data for either of these methodologies, several test sites are frequently pooled together for evaluation. Where a single site, or pair of sites, may not provide the large sample required, the combined accident histories may. This technique requires that all other variables be held constant across all sites (obviously impossible) or a large sample of sites be used so that the other variables "even out." This "evening out" technique may appear a bit loose to the rigorous experimental designer, but there are no practical alternatives and this approach has been widely accepted in the traffic engineering field. For example, results from a carefully designed study of 12-month accident experiences at 100 horizontal curves before and after installation of post delineators would receive wide acceptance.

Examples

One of the more dramatic research studies based on accident records analysis was the investigation of break-away sign posts conducted by Texas A & M University. Although this study is not related to delineation per se, it provides an illustration of the positive conclusions that can be drawn and the quick acceptance of the resultant recommendations by highway administrators and the general public. Unfortunately, few situations in the delineation area are so obviously tied to accidents themselves. (The break-away post concept, of course, does not deal with accident prevention, but rather with reduction of the severity.)

Many state highway departments have evaluated delineation treatments such as edge lines and post delineators as accident reducers. The following examples describe some of their procedures and the results obtained.

Since 1958, California has conducted a program to evaluate minor safety improvement projects, such as delineation, flashing beacons, guardrail, safety lighting. The paramount objective of the over-all study is to determine how effective the various types of improvements are in reducing traffic accidents. To accomplish this objective they use the before-and-after study procedure for numerous test sites. In the area of delineation, 32 projects involving various treatments of median striping, edge striping, and reflectorized guide markers were examined for changes in accident experience. The findings showed that only 5 of those projects showed improvement, whereas 27 did not. The discouraging findings were attributed to a large extent to the small accident experience, which hindered meaningful analysis (*36*).

In 1957, Ohio conducted a study to investigate the effect of pavement edge markings on two-lane rural roads. Sections of roadways with edge markings were compared with sections without edge markings (control sections). A total of nine pairs were selected and the study period consisted of 12 months before and after the installation of edge markings. Their findings, based on the chi-square test, indicate that accidents were significantly reduced in three areas: fatalities and injuries; night accidents; and accidents at intersections, alleys, and driveways. The report also points out the value of using a control section versus the use of a simple non-controlled before-and-after study. By using a control section, the time variability in accident rates can be taken into account and the proper adjustments can be made. Using a non-controlled-type study, the reduction of accidents would have proven to be insignificant (*10*).

Kansas conducted a study in 1960 to determine what effect pavement edge markings might have on accident rates. Their procedure was to use a controlled type of before-and-after accident comparison of 29 pairs of study sections. One-half of the sites received edge markings; the remainder did not have markings and served as control sections. The accident analysis, using a chi-square reliability test, indicated that there was no significant change in number of persons injured or in the total number of accidents. Accidents at intersections and driveways were significantly reduced, however (*2*).

Recently Idaho conducted an extensive study of 47 delineation projects using post delineators on two-lane roadways to determine how effective they are in reducing traffic accidents. A before-and-after study procedure with a minimum reporting time of 12 months was followed. The accidents included in this study were limited to left-roadway types. Only one category, night accidents at curves, showed a statistically significant reduction in accidents. A cost/benefit analysis showed a negative result. However, the author indicates that the installation of delineators "should not be dictated solely upon derived safety benefits" and cites factors of driving comfort and motorist preference that should enter into the decision (*8*).

Advantages

Some of the major advantages of the accident records analysis approach are:

1. The approach has high credibility with highway administrators and the general public.
2. An objective measure of effectiveness is obtained. Relative safety effectiveness of various alternative treatments can be stated in numerical terms.
3. The results are amenable to a cost-benefit analysis. Once hard data on accident reduction rates have been obtained, monetary values (if costs for accidents are established and accepted) can be placed on the benefits derived from the treatment.
4. The proposed treatment has a high chance of widespread implementation if found to be effective. If it can be shown that the treatment will save lives, injuries, and money, highway administrators and the general public will be willing to have the treatment applied extensively. It is much easier to justify relatively large expenditures for delineation if one can back up the request with research proven accident reductions.

Limitations

Although studies of this nature have considerable appeal, there are severe limitations and disadvantages, including:

1. An extensive commitment of time and amount of application is required—many sites must be treated and data must be gathered over a long period of time. This can be especially critical if the proposed treatment is not already an adopted practice. In California, for instance, the decision to make extensive installations of raised pavement markers was made approximately five years ago, and only now is it possible to make meaningful accident experience comparisons.
2. Heavy reliance on accident reports is required. Unfortunately, the reliability of accident reporting varies considerably from place to place at any given time and also with time itself. Several traffic engineers mentioned that fairly dramatic changes in accident rates have been recorded which, in reality, really amount to a change in the accident reporting policy of the state or local police. In fact, the Chief of the Traffic Research Bureau in one state indicated to project personnel that he did not attempt to make any evaluations on the basis of accident experience because their records were too unreliable.
3. Considerable time is required to reach reliable conclusions; hence, widespread installation of valuable improvements will be delayed.
4. New products or concepts cannot be evaluated in this manner, except through adoption for large-scale installations and study over a considerable period of time, as previously noted.

ADDITIONAL IMPLEMENTATION CONSIDERATIONS

In using the accident records analysis evaluation technique, it is important to keep the following factors in mind:

1. The definition of what constitutes an accident must be carefully considered and must be consistent throughout the study period.
2. The mechanism for reporting accidents (i.e., the data collection) must be consistent throughout the study period. Major changes in accident reporting policies will reduce the validity of the study.
3. The "before" and "after" study periods should be a minimum of twelve months in length so that seasonal variations in weather, recreational travel, etc., will not differentially affect the results.
4. In the selection of test sites and sampling periods, care must be taken to provide a large enough sample to ensure sensitivity of the tests. Too few accidents in the "before" period allow no room for improvement. (A total of 30 accidents for the "before" condition is a good target to shoot for in the absence of a statistical sample size determination.)
5. If the controls section approach is used, an attempt should be made to assure that the uncontrolled variables fall within similar ranges.
6. Although it is possible to arrive at a more meaningful estimate of the benefits of delineation treatments through this evaluation technique than the others discussed later, it should be remembered that only rarely can delineation decisions be made on that basis alone.
7. The major problem will be to eliminate the effect of changes in other variables during the long time period required for these studies. If the other variables cannot be controlled, the "brute force" technique must be employed—e.g., if a new type of stop approach treatment is installed at several hundred locations, the relative accident rates before and after can be compared with those at several hundred other locations where the treatment was not employed. (This obviously requires an extensive commitment to the treatment, and the test cannot be used to evaluate "shadings" of a treatment/system.)
8. Attempts to associate accident occurrence with any single factor (the specific defect approach) have met with a notable lack of success. A review of past research and reported correlations between a wide variety of measurable roadway variables and various indices of traffic safety indicates that even when the correlations are statistically different from zero, they are so small as to be of limited practical value, only rarely accounting for more than 20 percent of the variance (*131, 132*).

ERRATIC MANEUVERS

It is clear that effectiveness of delineation treatments/systems finds its ultimate expression in decreases in accident frequency and severity, and perhaps in terms of increased efficiency of traffic operations. Although a desire for a decrease in accident experience motivates most of the evaluation studies, it is also a source of considerable difficulty for the researcher, as outlined under "Limitations" in the previous section.

Several researchers have turned to erratic maneuvers (e.g., conflicts, near-misses) in an attempt to obtain relatively larger samples of data in shorter time periods. There is an implicit rational assumption that some correlation exists between the number of erratic maneuvers observed and the expected accident experience. (This correlation has been demonstrated in the case of intersection conflicts and accidents, but to date no correlation has been established between delineation and accidents.)

Examples

An approach to the near-accident category is reflected in the work of Perkins and Harris (*377*), who developed a conflict analysis for the evaluation of intersections. They define operationally 20 different objective criteria for traffic conflicts (or impending accident situations). As they describe it, ". . . essentially these traffic conflicts are defined by the occurrence of evasive actions, such as braking or weaving, . . . or a traffic violation." This method resulted in a much higher frequency count in shorter periods of observation and appears to be a sensitive indicator of certain types of effects, such as changes in regulatory signing.

In a study performed by the Michigan State Highway Department, one of the measures employed was a count of erratic maneuvers. In the words of the authors:

> Extreme erratic maneuvers were recorded separately. In order to avoid any question of judgment regarding what constituted an erratic maneuver, it was decided that . . . any vehicle that made two lane changes within the study section would be so classified . . . this classification also included any extreme movements such as stopping and backing up . . . radical movements across the gore, and vehicles stopping . . . and then proceeding.

This wide latitude of classification gave way, in a later study reported by Conley and Roth (*3*), to a more specific operational definition of five different erratic maneuvers and counts were maintained separately for each. An example of one such operationally defined erratic maneuver was: "Delayed exit—this is a vehicle that delays its exit long enough to drive across the painted gore or dirt."

Advantages

The major advantages of this research approach are:

1. It is possible to evaluate new products and/or concepts on a rational basis in a relatively short period of time, because development of an accident history is not required.
2. The before-and-after installation technique can be used to compare two or more alternative products, treatments, and/or concepts. Time variations in other variables will be minimized.
3. "Hard" data, with a strong rational basis, will be available to rank various alternatives.

Limitations

Major limitations and disadvantages of the erratic maneuvers technique are:

1. Definition of the meaningful erratic maneuvers is sometimes difficult. Unless a good case can be made for

the measures selected, the conclusions drawn from the research will not gain the required wide acceptance.

2. Although the problem is less severe than in the accident records analysis technique, it is frequently difficult to obtain the same experimental conditions for both the "before" and "after" studies—e.g., traffic volumes may vary, the driver population may vary (variations in local/nonlocal ratios with season changes, variations in the percentage of commuters with time of day, etc.), inaccuracies in data collection equipment and/or techniques with time.

3. Many of the most meaningful measures (e.g., percentage of drivers making "erratic" braking maneuver) are subjective in nature. It is difficult to define them in terms specific enough to ensure that the same results will be obtained by different observers.

4. The data that are intuitively most closely associated with accident potential (shoulder encroachments, sudden braking reactions) usually require fairly long data collection observation periods. For example, in approximately 20 hours of observing traffic on approaches to STOP signs, only one driver was observed to drive through the intersection with no apparent knowledge of the STOP sign.

Additional Implementation Considerations

1. The erratic maneuvers or conflicts to be counted must be carefully selected—i.e., a strong rational basis for the expectation that a reduction in erratic maneuvers will result in a reduction in accidents must be established. Varying weights can be assigned where necessary to designate the relative severity of the various erratic maneuvers under study.

2. The erratic maneuvers must be operationally defined —e.g., they must be clear on the basis of observable events, physical reference points, and time-distance relationships. In this manner the subjectivity can be reduced to a minimum. It is still desirable to use the same observer(s) for all conditions where possible.

3. Sample size decisions (i.e., number and length of observation periods) must take into account the frequency of each maneuver of interest, not just the total number. In the Perkins and Harris intersection study (*377*) it was concluded that it was possible to evaluate an intersection in three 12-hr periods. If very long times are required to collect an adequate sample of a specific erratic maneuver, the sample should be discarded even though the correlation between that maneuver and accidents seems strong. In this case, it will generally be more practical to define and measure pertinent traffic performance measures.

4. The study period should coincide with the times at which problems are evident or anticipated. For example, if most of the accidents occur at night, then obviously the erratic maneuvers should be counted at night rather than during the day. The same applies to rain, fog, peak vs off-peak periods, etc.

5. It is important to design the after study such that the uncontrolled variables will be in the same range for the before and after conditions—i.e., use study periods with similar characteristics; guard against extraordinary events.

6. Follow-up with accident records analysis as an accident history develops, where possible. The erratic maneuver method is not as decisive as an accident records analysis, but does give a reliable indication of how a delineation treatment affects traffic behavior. These data, then, can be evaluated by decision-makers as to their value in terms of justifying any additional expenses required.

TRAFFIC PERFORMANCE MEASURES

Traffic performance measures, as used here, include spot speeds, lateral placements, points of entry into ramps or deceleration lanes, gap acceptances and distributions, and brake application points. These measures have been used frequently in before-and-after studies to determine variations in traffic operations due to specific changes in delineation treatments and/or systems. A simple example of this type of study would be an investigation of the lateral placements and speeds at specific locations on a two-lane rural highway before and after installation of edge lines.

In a sense, this technique takes the evaluator one step further from the desired accident records analysis than the erratic maneuvers approach. The erratic maneuvers approach is suggested when an adequate sample of accident data cannot be obtained; the traffic performance measures are suggested when an adequate sample of erratic maneuvers cannot be obtained. This technique, then, is an attempt to estimate accident reduction potential through indirect measures. The widespread employment of this technique as a measure of effectiveness indicates that traffic performance measures are easy and practical to collect and possess sufficient sensitivity to reflect changes in treatment.

For all such intermediate criteria, however, there is one outstanding drawback—interpretation. The difficulty arises in the fact that statistical significance and practical significance are not necessarily the same. For example, a shift of 6 in. in lateral placement away from the center line following application of edge lines may be statistically significant and, therefore, one can conclude that the treatment has had an effect. The question remains, however: Is this change of 6 in. in lateral placement an improvement? In most cases, one cannot be certain, although some fairly convincing rational arguments can often be put forth.

The problem lies in improving the rationale involved in interpreting the results obtained. Perhaps the clearest statement of the point of departure for the logical derivation of the criteria suggested within this report was given by Michaels (*118*):

> In the broadest sense, what is an accident? Essentially it is some kind of error. . . . It is no different in kind from the unavoidable small wanderings occurring in a car's traveling a tangent section of highway. As a matter of fact, any deviation from an *ideal path* represents an error in system operation and differs from an accident only in degree; the accident requires a collision of some sort. The real distinction between an accident and any other driving error is that it is usually terminal and destructive.

At this point a persistent and important problem arises; namely, the definition, for any given situation, of an "ideal path." There is essentially no existing legal or physical one-and-only-one right way to negotiate any particular roadway geometry. It is precisely at this point that

Michaels' concept of reliability enters the picture. If the observed *variability* in performance of a sample of drivers is significantly lower in a situation with a particular delineation configuration, it can be contended (following Michaels) that this is a preferred design inasmuch as reduced total variability implies that it is now less likely that deviation or errors large enough to result in a collision of any sort will occur. That is, because the range of observed behavior responses has decreased, the probability that performance more deviant than that observed will occur has also been decreased and, therefore, accidents are less likely.

Basically, then, it is the position of the researchers that intermediate criteria can be employed in the evaluation of delineation treatments and that changes in variability across samples of drivers can be a major basis for the interpretation of the data.

In reviewing the literature on delineation studies it is seen that the variables studied are related to the test situation. For example, in a majority of the studies on the effectiveness of edge lining, spot speeds and lateral placement were the variables measured, whereas on studies of rumble strips and colored pavement for stop approaches, speed distributions, observance of STOP sign, and center line encroachments were the more appropriate variables. Table T-1 gives the traffic performance measures (and some of the potential erratic maneuvers, as they are closely related) that are appropriate measures for the given situations.

Examples

In 1963, the Arizona Highway Department reported (*41*) on a project to study the cost and effect of roadway delineation on rural primary highways. In addition to an accident analysis, measurements of vehicle speeds and lateral placement were taken. Clear sections that received no special treatment of edge lining or post delineators were used as controls and were compared to the test sections. The results indicated that night speeds increased when roadway delineation was installed—the increase being greater for edge lines than with post delineators. However, neither edge lines nor post delineators had any significant effect on vehicle placement, day or night. (Also, the accident analysis, based on a three-year period, indicated no significant changes.)

In another situation, Taylor (*16*) evaluated the use of colored pavement as a control and guidance device at through intersections with left-turn slots. He used three evaluative measures—approach speeds, traffic flow patterns, and vehicle lane positioning—to determine the effectiveness of the delineation treatment. The study period was too short to permit an analysis of changes in the accident experience. Two spot speed checks using radar meters were made at 600 ft and 200 ft from the intersection. The lateral placement measures were taken to determine the distance from the beginning of the left-turn lane to the point at which the turning vehicle completely cleared the through lane. Flow patterns obtained by time-exposure photographs of vehicles making left turns were used as a qualitative measure of the effectiveness of color. The results indicated that colored pavement did not affect the speed of vehicles in the through lane and had little effect on traffic flow patterns at night. However, the treatment was judged to be effective, based on the traffic flow patterns of vehicles entering the left-turn slot, as the vehicles were induced by the color treatment to enter the left-turn lane earlier.

In the current project, traffic performance measures were used in the evaluation of various treatments and concepts, as described in Appendices F, I, K, M, N, O, P, and Q.

Advantages

The major advantages of this evaluation approach are:

1. It is possible to evaluate new products and/or concepts on a rational basis in a relatively short period of time, because development of an accident history is not required.
2. It is possible to develop "hard" data for more subtle situations than can be studied through the erratic maneuver technique—i.e., meaningful traffic performance measures can be taken in situations where collection of erratic maneuver data would require inordinately long times.
3. The before-and-after installation technique can be used to compare two or more alternative products, treatments, and/or concepts. Time variations in other variables will be minimized.
4. Results of the studies will show which driver behavior patterns can be predicted and/or influenced through specific delineation treatments.

Limitations

Major limitations and disadvantages of this technique are:

1. Definition of the meaningful traffic performance measures is sometimes difficult. A strong rationale for the measures selected must be presented, or the conclusions drawn from the research will not gain the required wide acceptance.
2. Although the problem is less severe than in the erratic maneuver or accident records analysis techniques, it is frequently difficult to obtain the same experimental conditions for both the before and after studies—e.g., traffic volumes may vary, the driver population may vary (variations in local/nonlocal ratios with season changes, variations in the percentage of commuters with time of day, etc.), inaccuracies in data collection equipment and/or techniques with time.
3. Because a significant data collection effort is generally required it is usually not possible to evaluate the treatment across all variables—e.g., day vs night, site geometries.
4. In general, correlations between absolute values or variabilities in specific traffic performance measures and accident rates are not available. All conclusions rest on the rational assumption that such correlations do exist. (See Appendix Q for a preliminary study in this area.)
5. Even if it is accepted that a reduction in variability of a specific traffic performance measure does indicate a probable reduction in accident rates, the nature of this correlation cannot be defined—e.g., what percentage reduction in accidents can be anticipated if the variability

of lateral placement in horizontal curves is reduced by 50 percent?

6. The effectiveness of the various treatments, as measured by improvements in traffic performance measures, cannot be stated in dollar terms for cost-effectiveness studies.

Additional Implementation Considerations

1. Selection of appropriate traffic performance measures is the most critical task. These measures must reflect variations in driver behavior that are related to accident occurrence (if that is the major intent of the treatment under study). Unfortunately, definitive guidelines are difficult to establish because the number of combinations of geometric situations, potential treatments/systems, weather conditions, and traffic performance measures is unlimited.

2. It is important that interpretation guidelines be established before data collection. Instead of installing delineation treatments and conducting a study to "see what happens," it is preferable to evaluate the data against a predetermined hypothesis. For example, it is not appropriate to conclude that edge lining is effective if the mean lateral placement is moved 1 ft farther from the edge line. Prior to testing, it should be hypothesized that a certain placement (or decrease in variability) is desirable and any movement toward that would be a measure of the effectiveness of the delineation treatment.

3. In most cases, a criterion based on changes in the variability of driver performance is to be preferred over simple, average shifts in placement, speed, etc., as this avoids judgments regarding the definition of "ideal path."

4. Practical limits must be observed with the variability criterion because a reduction in group variability can be undesirable if the absolute values of certain parameters fall outside an acceptable range. (For example, a delineation treatment for a sharp curve that is so dramatic as to cause everyone to slow to the point of stopping.)

5. Care must be taken in data collection so as not to cause drivers to exhibit atypical or unnatural behavior (as, for example, might occur by use of road-tube speed traps, highly visible radar meters).

6. Because the sample size required for statistically reliable data is dependent upon factors such as error tolerance and magnitude of treatment effect, these calculations must be made according to the specific purpose and conditions under which the evaluation is to be conducted. It is generally possible to obtain samples of at least 100 vehicles when measuring characteristics such as speed or lateral placement in relatively short data collection periods. However, much longer data collection periods (or smaller samples) will be necessary when measuring passing behavior at certain test sites, gap acceptance, etc.

7. As in the case of the erratic maneuver technique, the traffic performance measures should be taken during the time of day and under the environmental conditions at which the problem exists if these parameters have been identified.

8. The before and after study periods should encompass similar traffic and environmental characteristics.

9. In interpretation, differentiation must be made be-

TABLE T-1

TRAFFIC PERFORMANCE MEASURES (AND ERRATIC MANEUVERS) FOR DIFFERENT HIGHWAY SITUATIONS

SITUATION	TRAFFIC PERFORMANCE MEASURE
Curve (horizontal)	1. Spot speeds: Upstream, Entry, Apex, Exit, Downstream 2. Lateral placement 3. Encroachments: Shoulder, Center line 4. Brake applications
Passing zone	1. Passing frequency 2. Passing and return type 3. Passing time/distance 4. Number of abortive passes 5. Conflicts with oncoming or overtaken vehicles
Pavement width transition (lane drop)	1. Spot speeds: Upstream, Vicinity of sign, Beginning taper, End taper 2. Distribution of lane changes 3. Merging conflicts 4. Encroachments 5. Lateral placement through transition area
Merging area	1. Merge speed profile 2. Conflicts with through stream 3. Distribution of merges 4. Delay
Diverge area	1. Distribution of points of entry into inside lane 2. Distribution of points of entry into decel. lane 3. Mainstream speed 4. Decel. lane speed profile 5. Speed at gore area 6. Erratic movements at gore area 7. Speed on ramp
Turn (with decel./storage lane)	1. Location of lane changes required to enter decel. lane 2. Spot speeds: Upstream, Entry 3. Point of entry into decel. lane 4. Erratic maneuvers 5. Conflicts with opposing vehicles and with through vehicles 6. Time through intersection
Stop approach	1. Speed profile 2. Lateral placement 3. Distribution of brake applications 4. Encroachments on cross roadway 5. Erratic deceleration

tween statistical significance and practical significance. As discussed earlier, a shift of 6 in. in lateral placement away from the center line following application of edge lines may be statistically significant, and, therefore, one can conclude that the treatment has had an effect. Is the treatment effective? This is a different question, because it implies improvement. The problem is further complicated by the fact that delineation treatments can rarely be evaluated on safety alone; consideration of the possibility of improvements in all aspects will be required in the decision-making process.

DIAGNOSTIC TEAM

Because traffic studies and accident evaluation take time and money, the traffic engineer frequently must revert to his engineering judgment for evaluating a given problem and subsequent treatment. Presumably, the traffic engineer is adequately trained in his field and can determine where a hazardous situation exists and the treatments that may be applied to alleviate or eliminate the hazard.

Usually the engineer is alerted to a certain problem area either by an irate citizen or by the knowledge of a high accident rate. Inspection of the site leads him to an intuitive judgment that a certain factor is causing the problem. He then applies a treatment, such as a traffic signal, that he believes will reduce the problem. If no further "bad news" is received, the treatment is labeled a "success." The merits of this evaluation procedure lie in the ease of application. However, it depends on one person's subjective evaluation (albeit the individual may be an expert in the area).

To lend more credibility to this type of subjective evaluation a group of engineers (and sometimes members of other pertinent disciplines) may be asked to evaluate the problem and make recommendations as to the solution. Here the chance for error is somewhat reduced because the decision is a concensus rather than one man's judgment.

In this approach, the proposed treatment and/or system is installed at a few locations. These installations may be on operating highways or, frequently, they are temporary installations on off-highway facilities or unopened sections of roadway. The installations are then inspected and subjectively evaluated by the diagnostic team.

An example of a study that might be conducted in this manner would be to install post delineators at various spacings along a tangent section of roadway, then have the diagnostic team drive the route, observe the delineator patterns, and arrive at a concensus as to which is "best." The analogy is often made with this team approach in the medical profession. Richards, et al. (*33*), describe this analogy in their diagnostic team approach of rail-highway grade crossing safety evaluation, as follows (one can easily paraphrase this description in general highway safety terminology):

> The medical doctor or team of doctors employs a series of clinical tests to systematically check all of the functions and response systems in the human body. When a malfunction is discovered, an attempt is made to identify the cause of the malfunction by comparison with symptoms previously found to be associated with such illnesses. Although precise identity of the illness is not always possible, the probability of existence of various illnesses or malfunctions may be computed. From these computations, decisions are made to administer medicines and/or perform surgery in an attempt to correct the disorder. As a part of the clinical procedure the patient's response to the remedial action is observed. In the event an expected response does not occur, a reevaluation of the probability of correct diagnosis is made. Since the procedure is based on an analysis of response to remedial treatment, changes in diagnoses are relatively frequent.
>
> Employing the diagnostic procedure, medical and surgical techniques are applied in a systematic manner to cure illnesses and correct body malfunctions. Many of the techniques developed in the medical application of the diagnostic technique to correct complex body systems may be useful to the proper identification of disease patterns at many hazardous rail-highway grade crossings. From the knowledge gained through the application of the diagnostic techniques, the safety epidemiologist may postulate theories relating to the diseases that he has identified.

It is possible to rank various alternative treatments on a numerical basis through subjective scaling techniques. For example, diagnostic team members can be asked to assign a rating from 0 to 100 (0 being a very poor or totally inadequate treatment; 100 indicating an ideal or perfect treatment) for each treatment under study. Obviously these ratings cannot be correlated directly with anticipated accident rates, but they can be used to rank-order the treatments and indicate some scale relationship among them—e.g., treatment ratings of 90, 80, and 40 for three alternative treatments are more informative than ratings expressed as "high, middle, and low." Also, although the inputs are not direct, these readings can be helpful in cost-effectiveness analyses.

Example

The Texas Transportation Institute is conducting a large-scale evaluation of the diagnostic team approach and developing study procedures for diagnostic studies of highway visual communications systems. Because the highway communication system consists of many elements (e.g., signing, geometry, roadway delineation, and illumination) that interact with each other, these elements are being studied collectively by the TTI researchers.

Such a research endeavor lends itself to the advantages of a diagnostic study. Teams of researchers from TTI, highway officials, law enforcement officers, and laymen "diagnose" data obtained from drivers who travel the prescribed routes. The drivers relate to the team, via a tape recorder, the problem they encounter in navigating their way from place to place. At the end of a driving run, a review session is conducted where the team members identify the problem areas and recommend methods to resolve those problems.

Advantages

The diagnostic team approach has the following advantages:

1. It is a relatively simple evaluation. It does not require elaborate data collection and analysis; the study can be accomplished with relatively little time and effort.

2. The diagnostic team can be chosen so that it contains experts from all pertinent disciplines and interests—e.g., state traffic engineers, maintenance personnel, psychologists, materials experts, experienced researchers. Thus, all aspects of the differing treatments can be assessed at one time. Also, this provides an opportunity for interplay and mutual assessment of the various aspects of the problem.

3. The diagnostic team members will be aware of current related research and effectiveness evaluation techniques pertinent to the problem at hand.

4. The diagnostic team members can bring their total experience related to traffic characteristics, driver reactions to similar treatments in the past, maintenance problems, etc., to bear on the problem. It is possible, thereby, to assess factors that cannot be measured in an objective fashion, or even enumerated.

5. The rating scheme permits assessment of the relative merits of various alternatives. These numerical effectiveness ratings will be useful in later over-all evaluations.

Limitations

The limitations and disadvantages of the diagnostic team approach should also be recognized:

1. The diagnostic team approach provides only a subjective evaluation of the treatments/systems being tested. (However, the rating schemes can be used to derive "numerical" data.)

2. It is generally not feasible to conduct the study under a wide variety of weather conditions, roadway geometries, etc.

3. The diagnostic team members are aware of the specific treatments under investigation and will focus their attention on the particular problem being studied (as opposed to the ordinary driver, whose attention will almost certainly be directed to other matters). Hence, differences in delineation treatments that may be significant to the diagnostic team may be imperceptible to the ordinary driver. If this is so, perhaps the significance has no meaning, or perhaps the difference will be subconciously noted by the ordinary driver. A decision is required in each instance.

4. Similarly, the diagnostic team may be too familiar with the situation and geometry of the study site—e.g., in studying possible delineation of curves or ramps, prior knowledge of the specific geometry may influence the team member's assessment of the clarity of the message.

5. Some treatments and/or systems depend heavily on coding with which the team members may be familiar and consider clear and obvious, whereas the ordinary driver may not know the code.

6. Some of the team members will be temporarily removed from their primary duties. To be effective the members should remain on the team for the duration of the project. This requires that the personnel temporarily leave their primary jobs; a situation that in many cases cannot be accommodated.

7. Frequently, a complicating factor is that all the experts do not agree as to which treatment is best.

Additional Implementation Considerations

1. To avoid undue influence by any one team member, a procedure that allows for the pooling of independent, nonconsultative judgment is preferred.

2. Team members should be trained or practiced in the types of judgments or ratings to be performed so that consistency of estimates from one occasion to another can be reasonably assured.

3. Frequent checks should be made on the degree of concensus derived on the basis of the pooled independent judgments. Although the judges, particularly if they are from varied backgrounds, cannot be expected to agree all the time, too much disagreement calls for an investigation of the applicability of the specific test being utilized.

4. The diagnostic team should consist of approximately ten members. Smaller groups lack the diversity that is one of the strong points of the technique, and also it is possible that the group will be unduly influenced by one strong member; larger groups become unwieldy, and it is difficult to arrange mutually convenient meeting times.

5. A general procedure for using the diagnostic team technique involves the following:

   (a) A briefing of the team as to purpose and objectives of the study.
   (b) Driving the study area.
   (c) Completion of a questionnaire.
   (d) Inventory of physical characteristics.
   (e) Critique and discussion period.

6. Structure the test as much as possible before conducting the evaluation; it is important that all members know what they are evaluating and on what basis. Side comments can be valuable, of course, and must still be permitted if the benefits from the broad experience of the team members are to be realized.

7. If scaling techniques are being used, they should incorporate appropriate sensitivity—i.e., the scale may be "good, medium, poor," or permit ratings from 0 to 100 in unit increments (scales incorporating more than ten steps will seldom be desirable, however). It is helpful to provide a supplemental, verbal definition of the scale; e.g., 0—does not apply; 1—rarely important; 2—sometimes important; 3—usually important; 4—most significant.

8. Conduct the study under the critical traffic and environmental conditions when possible.

9. It is best to install the treatment under study at more than one location, but still important that the time interval between viewing comparative treatments be kept to a practical minimum.

DRIVER SURVEYS

The driver survey approach differs from the diagnostic team primarily in that the observers of the treatments being evaluated are not trained traffic engineers and/or associated researchers. Also a much larger sample is generally used in this type of study than in the diagnostic team approach. (Diagnostic teams are usually limited to 10 members or less, whereas driver samples frequently exceed 50 subjects.) The same types of evaluations are often made through this approach as are studied through the diagnostic team method.

The driver response method need not always be conducted in an actual field situation. Often it is not advisable to test a new device without some indication of the probable motorist reaction to it. For this reason and others, the filmed-ride technique has been used to advantage by researchers in evaluating drivers' reactions to signing. Burg and Hulbert used this technique in their evaluation of lane drop signing. Their procedure was to take motion pictures viewed from the driver's position in a moving vehicle. The films were then shown to a large group of subjects and appropriate questions were asked to elicit the information desired. The procedure does have the disadvantage of placing the driver in a controlled environment and not subjecting him to the many other variables that influence his driving behavior. However, it also has the advantage of focusing the driver's attention on the problem at hand and isolates the variable to be studied.

One other procedure that involves driver response is to examine a large sample of people as they drive through an area. This can be done either by having an observer in the car with the driver or by filming the test car as it is driven through the test section. Both the size and content of the driver sample are critical, for they must adequately represent the total driver population. This procedure has the inherent disadvantage that the drivers are aware that they are being studied and will not drive naturally.

Many highway departments have employed the driver survey technique in one form or another. The usual procedure is to stop randomly selected cars after the test section and interview the drivers, or to stop all the vehicles and hand the driver a post card and request that he answer the questions and return the card by mail. With the latter procedure, the drivers are more likely to forget their reactions as they drove through the section. The former procedure has the disadvantage that the driver may be irritated that he is being delayed and his answers may not reflect his true feelings.

Whether or not there should be advance publicity through the media depends on the desired results. For example, in evaluating the use of color coding it might be desirable to interview drivers without prior publicity to determine if the public can learn the color code. A follow-up study after widespread news coverage would then reveal how publicity influences the learning phase.

A variation of the driver survey technique is to document public opinion as reflected in letters to the state highway department and/or local newspapers. Sometimes letters are solicited through "requests for opinions" in the newspapers. State highway departments appear to be responsive to public opinion as expressed in this manner.

Several highway department personnel indicated that the "large driver sample" evaluation technique has been the primary means of evaluating the effectiveness of pavement edge lines. This is popular with the public and even those who do not agree that it should be used admit that public acceptance is a well-established fact.

Examples

The driver survey can be helpful in obtaining information on driver perception and awareness. It is interesting to compare the results of three separate studies of exit ramp color coding by Ohio, Michigan, and Minnesota. The Ohio and Michigan studies were similar in respect to advance publicity and the format of the questionnaire. The color coding was mentioned at the time the driver was asked if he had observed the system. In the Minnesota questionnaire, no mention was made of the delineation system and advance publicity was not given. The results are summarized in Table T-2.

In the Ohio study (*18*), the questionnaire was designed to test the drivers' awareness of different shapes and colors of pavement markings over a highway section they had just driven (a transition from 4-lane to 2-lane highway). Questions were asked to extract the following information: (1) what the driver had seen; (2) his interpretation of the marking; and (3) his opinion of the marking.

It should be recognized that results of a driver survey like the one used in Ohio can provide only a relative measure of driver awareness or perception. It is interesting to note that only 16 percent of the 94 drivers interviewed while the standard broken white lines were installed could identify the pavement markings on both the 2-lane and 4-lane sections, which indicates that drivers are not fully aware of markings in their everyday driving. (The interviewer used specific questions: Was it yellow or white? Was it solid or broken?)

Although the driver survey can be used to measure driver awareness, it is not always a reliable indicator of driver performance. Although a driver might not be consciously aware of a delineation device, it might have an effect on his driving performance. Minnesota (*1*) made a study of color-coded exit ramps using both yellow and blue for pavement markings, post delineators, and exit signs. The study procedure consisted of both a driver interview and measurements of speed, placement, and erratic maneuvers. The results indicated that although only 24 percent of the 1,319 drivers interviewed indicated an awareness of the color treatment, the physical measurements of speed and point of exit showed significant effects on driver performance. With the yellow-coded exit ramps, drivers exited slower and had an earlier point of exit, whereas

TABLE T-2

RESULTS OF EXIT RAMP COLOR CODING STUDIES BY THREE STATES

STATE	DRIVERS (%) WHO: NOTICED SYSTEM	FELT CONCEPT WAS GOOD
Ohio	91	88
Michigan	93	86
Minnesota	24 [a]	— [b]

[a] 64 percent when asked in a more specific manner.
[b] Question not asked.

with the blue-coded exit ramp drivers had higher exit speeds and later points of entry to the exit when compared with the control exits.

Laboratory-type driver surveys were used in the studies on coding information value and target value detailed in Appendices G and H.

Advantages

The driver survey procedure has the following advantages:

1. It is more likely that differences noted by the subject will also be apparent to the total driver population than is the case with the diagnostic team approach.
2. Large samples can be obtained with relatively little effort and expense. Even where it is necessary to hire test drivers, the costs are frequently less than for other validation methods.
3. Prejudices of the researchers and prior knowledge of the situations, codings, etc., can be removed from the tests.
4. It is still possible to use the rating scheme discussed under the diagnostic team approach to obtain scaled evaluations of the various alternatives. Hence, numerical effectiveness data can be generated to assist in later over-all evaluations.

Limitations

1. A major problem is to obtain a sample representative of the total driver population. If drivers are recruited, a bias already exists in that only certain types of drivers will respond; if the driver interview technique is used, the mix of drivers will vary from place to place and from time to time at the same place.
2. The results obtained are influenced by the interviewer and the questionnaire format. Care must be taken that the drivers are not "worked" into one answer.
3. As in the case of the diagnostic team, it is generally not feasible to conduct a study under differing weather conditions, roadway geometries, etc. Flexibility in test location and timing will depend to a large extent on the test preparation required—e.g., considerable flexibility is available if the "passing driver interview" technique is used, whereas major time and money expenditures are required if the subjects must first be recruited and trained, and are required to report to certain sites at certain hours.
4. Agreement may not be obtained among the subjects. An evaluation must be made to determine if this is merely difference in opinion of the delineation treatment being studied, or whether these differences arise from minor variations in the test procedure (e.g., the use of different interviewers and/or instructors).
5. For tests other than interviews of drivers after the fact, a major problem is that the test subjects know they are subjects and that their performance is being measured. This undoubtedly affects the manner in which they drive and/or their attention to traffic-related devices. It is sometimes possible to remove part of this bias by telling the subjects that you are interested in or are measuring a certain parameter while you are actually measuring another parameter.
6. As with the diagnostic team technique, only subjective evaluations are possible.
7. This technique is the least appropriate of those discussed for the evaluation of the safety aspects of delineation: it is more useful in the evaluation of driver comfort, convenience, aesthetics, etc.

Additional Implementation Considerations

1. Questionnaires should be developed and extensively pretested and revised before use in the actual study work. This is essential to ensure that the data are not biased by leading questions or rendered uninterpretable by ambiguous answers.
2. When possible, return mail surveys should be avoided, because respondents are often measurably different from nonrespondents. When such a survey is used, a method for checking on a sample of the nonrespondents should be incorporated.
3. Interpretation of survey results must be undertaken with clear knowledge that variables different from all other evaluation types are being measured. In general, it cannot be expected that the average driver is attuned to safety aspects of delineation—usually those treatments that make the driver feel most comfortable, and that are simplest in interpretation, will be rated high. The applicability of the results to accident reduction requires careful analysis by the researcher.
4. Although the driver survey can be used to measure driver awareness, it is not always a reliable indicator of driver performance. A driver might not be consciously aware of a delineation device, but it might affect his driving performance.
5. Whether or not there should be advance publicity through the media depends on the desired results.
6. Sample sizes of 100 drivers will generally be possible and will usually be adequate to detect differences in treatments that have practical meanings. The time requirements will depend on the nature of the test—in the worst case, drivers must be hired, trained, accompanied by the researcher through the test course, and then interviewed.
7. The comments relative to scaling in the discussion of the diagnostic team technique are also pertinent to the driver survey technique.
8. Depending on the problem under investigation, it may be desirable to discuss the experiment with the driver before the test (interpretation, coding studies, etc.), or to conduct the test with no instruction and then ask appropriate questions (awareness studies).

ADDITIONAL COMMENTS ON EVALUATION TECHNIQUES

A variety of experimental designs can be used with any of the evaluation techniques. The choice of design will be governed by a number of factors and is too complex to discuss here. Two pertinent general comments can be made, however; first, the investment of time and effort in careful experimental design is well worth the price, because the validity of the results and the usefulness of the generalizations to be drawn from the study are determined at this stage; second, the advantages and limitations of the various techniques interact with the design selected. This latter point means that although the limitations cannot be totally overcome, they can be minimized by good design and, likewise, the advantages can be negated by poor selection or sloppy execution of a design. For example, use of a before-and-after-type design is vulnerable to changes that occur during the time it takes to complete the study; accident records techniques require more time and are therefore more vulnerable. Control sites designs minimize the influence of time-dependent factors, but are susceptible to chance fluctuations at each site.

If erratic maneuvers and/or traffic performance measures are being taken, this susceptibility to chance variations in uncontrolled variables is increased because of the relatively short time periods involved in the data collection (thereby eliminating the evening out that would attain over longer time periods). On the other hand, the effect of long-term trends in traffic performance will be minimized and major discrete changes (such as opening of a new shopping center) can be anticipated and site selection can be governed accordingly.

In either of the two basic types of design (before/after or control sites), the investigator is attempting to control (actually or statistically) variables that could adversely influence his results or confuse his interpretation. A number of these variables are obvious (e.g., traffic volume, composition, geometry, driver population). The problem lies in the fact that in any form of field research the potential for fluctuations in the variables during the study period is large, and no effective means of controlling these variables is available—in fact, the changes frequently are such that they cannot even be anticipated or measured.

Another major problem in the evaluation of new delineation treatments is the uncertainty of the carry-over of observed results from a test installation to the general situation—i.e., it is not certain that people will react after repeated and consistent exposure to a new treatment in the same manner that they do to a new and unusual test installation. This has both a positive and a negative aspect—it is possible that driver performance will improve with general use because the drivers then learn the code, whereas they do not realize the significance of certain treatments when they come upon them unexpectedly; or they may react favorably to a changed delineation treatment primarily because it is different, in which case the improved performance may disappear when the treatment becomes general and the uniqueness is lost.

RELEVANT COST-EFFECTIVENESS METHODOLOGIES

This section defines, evaluates, and recommends cost-effectiveness methodologies that the researchers believe are best suited to evaluate delineation treatments/systems. Procedures for estimating the cost of delineation treatments under various conditions of data availability, and guidelines for estimating the benefits of delineation treatments are presented. The procedures are discussed under three major categories, depending on the types of data generally available:

1. Accident records. Here it is assumed that very good accident histories are available for the various sites under consideration when before-and-after studies are performed. When parallel studies are performed, the time span of the accident records need not be as great.
2. Intermediate measures. This category includes both the erratic maneuvers and the traffic performance measures techniques. As stated previously, when an adequate accident history is not available the analyst may use these measures to evaluate the effectiveness of various delineation treatments.
3. Expert opinion. This method can be used for the evaluation of delineation systems when no other data are available from either accident records or intermediate measures, or it can be used as a supplement to the accident records or intermediate measures techniques when certain parameters cannot be estimated quantitatively.

Driver surveys are not considered in this section because this technique is not amenable to the evaluation of delineation treatments when the emphasis is placed on safety. As stated previously, this method is more suitable for evaluating other benefits of delineation, such as driver comfort and convenience, and aesthetics.

Methodology

The first step in any cost-effectiveness analysis is to clearly define the objectives of the proposed treatments/systems. When alternative delineation systems are being considered, the objectives will usually consist of reducing accident rates as a whole, reducing the severity of accidents, or reducing a specific type of accident (such as the number of run-off-the-road accidents on horizontal curves). Other objectives may also be considered, such as time savings, reduction in driver strain and discomfort, and/or a reduction in nonuser costs.

The second step is to define the constraints that may limit the scope of the analysis. For example, the number and type of locations under consideration must be specified. Cost and effectiveness definitions also enter into the constraints. It should be stated whether the analysis is to be conducted under the assumption of a fixed budget constraint, or a fixed effectiveness requirement, or whether the analysis is to determine the most cost-effective treatment without regard to budget or effectiveness requirements.

Cost Estimation

Critical in the evaluation of the costs and benefits of delineation treatments is the choice of the analysis period, which is also called the "planning horizon." If this period is too long, both costs and benefit estimates can be subject to a great deal of uncertainty toward the end of the period. The estimation of the planning period is usually a highly subjective process, because it depends on estimating, among other factors, the service life of each component of each treatment in the system. It is recommended that the analysis period for the evaluation of delineation treatments be a maximum of ten years. All treatments should be evaluated over a common analysis period and replacement assumptions should be made for those alternatives whose useful lives expire before the end of the period. The usual replacement assumption is that treatments will be replaced in the same manner in which they were first instituted. This assumption is reasonable and should be used in the analysis of delineation treatments.

The costs of all treatments must be defined along some common basis. This common basis is primarily up to the analyst—examples are per foot of roadway and per location delineated.

Costs should be broken down into initial investment and maintenance costs. All costs must be reckoned with on the same time basis, so it is necessary to discount costs that accrue over time back to some common point in time. Although no firm recommendation can be given as to the proper interest rate for this computation, a rate between 4 and 10 percent is considered highly justifiable. The most likely estimate is around 6 to 7 percent, the rates currently most commonly used.

Sunk cost is the money that has been spent in the past and thus has no relevance for future systems. That is, it should not be counted as a cost of the various delineation treatments under consideration. This cost should be considered only when it affects different delineation treatments in different ways. For example, if posts have already been installed along a roadway, the cost of installing post delineators is considerably reduced. The presence of these posts, however, has no relevance to the cost of either raised pavement markers or painted edge lines and center lines and should not be counted as a cost of these alternatives. If, however, it is necessary to remove these posts before another treatment can be applied, the cost of removal can be considered as a cost of the alternative treatment.

Currently, there is much discussion in the literature with regard to taking inflation into account in the analysis. However, it is only necessary to take into account changes in the relative prices of costs and benefits, and not changes in the general price level. The analyst must have available a very good forecast for the envisioned changes in relative prices before a realistic appraisal of the differential effects of inflation on costs and benefits can be made. Presently, forecasting inflation involves so many subjective judgments that reliable estimates are not generally available. Thus, it is probable that more harm than good would come from attempting to account for inflation in the analysis. However, if the analyst has reliable information that certain costs will rise shortly, he can incorporate these known changes. An example is where labor contracts will expire shortly, and increases in associated costs are expected.

Investment and maintenance costs should be broken down into subcategories so as to take into account explicitly all the costs involved. These subcategories include the costs of materials and supplies, labor costs, and machinery operating costs and depreciation. Estimates of these costs can be obtained in a variety of ways. If the particular delineation treatments under consideration have been installed in the past, the engineer may be able to obtain accurate estimates of the costs from records in his state or district. Cost data can also be obtained through review of the literature concerning current practices. However, these data may not reflect the unique conditions that are present in a particular state, and thus an appropriate adjustment may be required.

Another method of obtaining cost estimates is to examine the cost involved in installing and maintaining devices and improvements that are similar in character. For example, the labor cost involved in installing posts for small signs may be similar to that of installing post delineators. Another approach is for the engineer to rely on his own intuition and judgment regarding the labor expense and the amount of materials and machinery operation and depreciation costs that may accrue when treatments are installed and maintained. A group of experts can also be consulted in this regard. Appendix E outlines procedures that can be used to integrate expert opinion into the analysis.

No matter which method is used to estimate the costs involved in installing and maintaining delineation treatments, the costs cannot be stated with complete confidence. Uncertainty also will surround the estimates of the benefits of delineation treatments. Thus, there is need for the engineer to account for the effects of uncertainty on his estimates of both costs and benefits. Several techniques are currently available in the literature to account for these uncertainties. These include contingency analysis, *a fortiori* analysis, Monte Carlo simulation, and sensitivity analysis. A further discussion of these methods is given in Appendix E.

Benefit Estimation

The primary benefits expected to result from the installation of delineation treatments are due to the reduction in accident rates, vehicle operating costs, in time spent on the highway, and/or driver strain and discomfort. Although each of these sources of benefits is important and should be taken into account in a comprehensive cost-effectiveness analysis, the single most important source is accident reduction. Thus, procedures are outlined so that the engineer can evaluate delineation treatments primarily on the basis of how they affect accident rates.

Accident Records Approach

One of the most common methods used to evaluate all types of highway improvements, including delineation treatments, is to observe changes in accident rates. Either the before-and-after or parallel study methodology can be employed, using accident rates as the criterion. There are, however, numerous problems involved in implementing this approach to the evaluation of delineation treatments, as outlined earlier in this appendix.

To perform a cost-effectiveness analysis of delineation treatments using changes in accident records as the criterion, the engineer should:

1. Conduct a before-and-after or parallel study taking into account the considerations concerning methodology presented earlier.
2. Calculate treatment effectiveness as determined by changes in the accident records.
3. Perform a statistical analysis to determine which

treatments under consideration resulted in statistically significant accident reductions.

4. Eliminate from consideration treatments that have been shown to be ineffective on the basis of the statistical analysis.

Whether the engineer uses either the before-and-after or the parallel study approach to evaluate the treatments under consideration, the results of the fourth step will be a set of delineation treatments ranked by the number of accidents reduced, or the percentage of accidents reduced. These accident reduction parameters must then be compared with the cost of each treatment. To make this comparison valid, it is necessary to reckon with both costs and benefits on the same basis; for convenience, this common basis is usually chosen as dollars. It should be noted, however, that some researchers have attempted to evaluate safety improvements without placing a dollar cost on accidents by assuming some sort of weighting scheme instead of actual dollar values. This approach, however, implicitly involves intuitive and judgmental evaluations of the relative costs of various categories of loss.

Because it considerably simplifies the analysis, it is recommended that highway engineers change the accident reduction parameters into dollar values by applying the appropriate accident costs as determined from studies reported in the literature. Thus, for each category of loss (i.e., property damage, injury only, and fatalities) an appropriate dollar figure is assigned. Examples of justifiable figures are those from the Washington study (*371*), which were modified slightly by Arthur D. Little, Inc. (*349*) and are presented in Appendix E.

The next step in the cost-effectiveness analysis of alternative delineation treatments involves ranking the alternative treatments as to their acceptability and choosing the particular treatment the engineer considers best. This involves choosing a criterion to rank the alternative treatments. Although there is much discussion in the literature concerning the use of benefit-cost ratios and rates of return as valid criteria, it is believed that the most desirable criterion is net benefit. This criterion eliminates many of the problems involved with the other two criteria, as discussed in Appendix E. Hence, the analyst would determine the expected benefits over each year of the planning horizon, discount these benefits back to the present, and subtract from them the present worth of the costs of each treatment. The alternative that exhibits the highest net present worth of benefits minus costs should be recommended for implementation. Fixed budget or effectiveness requirements necessitate slightly different procedures, also outlined in Appendix E.

If the analyst wishes to take the intangible costs of accidents into account, it is recommended that he use either the approach developed by Little, Inc. (*349*), or the one developed by Widerkehr (*373*), both of which are discussed in more detail in Appendix E.

Intermediate Measures

Because of the many difficulties involved in applying the accident records approach to the evaluation of highway improvement projects, several researchers have turned to erratic maneuvers and intermediate criteria as evaluative measures. Examples of erratic maneuvers are sudden braking, sudden lane changes, swerves, etc. Examples of intermediate criteria are means and variances of vehicle speeds, placements, accelerations, and decelerations. These measures can be used to evaluate delineation treatments under two conditions:

1. Statistical validation of the relationship between accident experience and intermediate criteria or erratic maneuvers is present.
2. No statistical validation exists for either measure.

Although condition 2 is the more prevalent, guidelines are outlined for studies under both conditions.

When statistical validation of intermediate criteria and erratic maneuvers is present, the engineer's job is considerably easier. The statistical validation indicates that a particular maneuver or set of maneuvers is highly correlated with accidents, or that certain intermediate criteria are highly correlated with accident rates. In addition, the results are directly amenable to a cost-effectiveness analysis of delineation treatments.

If validation is present, some functional relationship linking accident rates to erratic maneuvers or intermediate criteria exists. This functional relationship can be in terms of a correlation coefficient or a regression coefficient. By using these relationships, the engineer can transform changes in these measures into expected accident reductions.

Thus, to perform a cost-effectiveness analysis of delineation treatments by the use of either intermediate criteria or erratic maneuvers as the measure of effectiveness, where validation of these measures is present, the engineer should:

1. Conduct a before-and-after study or parallel study of delineation treatments by use of either intermediate criteria or erratic maneuvers as the measure of effectiveness rather than accident rates.
2. Calculate treatment effectiveness as determined by changes in these measures.
3. Perform a statistical analysis to determine which treatments under consideration resulted in statistically significant changes in these measures.
4. Eliminate from consideration those treatments shown to be ineffective on the basis of the statistical analysis.
5. For the remaining treatments, substitute the changes in the effectiveness measures into the functional relationship derived from the statistical validation. This functional relationship will transform changes in these measures into changes in accident rates.

Statistical validation of intermediate criteria and erratic maneuvers is the exception rather than the rule. If the engineer decides to use erratic maneuvers or intermediate criteria as measures of delineation treatment effectiveness, he faces many problems. Not only must he determine which erratic maneuvers and intermediate criteria to measure, but he also must integrate his results into a cost-effectiveness analysis of the treatments under consideration. Although the results may not be as clear-cut as the case in which validation is present, the engineer nevertheless can make some decisions on the basis of how delineation treatments affect these measures. He must, however, assume that changes in these measures are in some way related to changes in accident rates.

To perform an analysis of delineation treatments by using either intermediate criteria or erratic maneuvers as the measure of effectiveness, where validation of these measures is not present, the engineer should:

1. Conduct a before-and-after study or parallel study of delineation treatments by use of either intermediate criteria or erratic maneuvers as the measure of effectiveness.
2. Calculate treatment effectiveness as determined by changes in these measures.
3. Perform a statistical analysis to determine which delineation treatments under consideration have resulted in statistically significant changes in these measures.
4. Eliminate from consideration treatments that have been shown to be ineffective on the basis of the statistical analysis.

After the engineer has completed these steps, there are various ways in which he can proceed to evaluate the remaining treatments. If only one hazardous location is under consideration, he may want to implement the most effective treatment regardless of cost. Because the costs for common delineation treatments are somewhat similar, and because the costs of accidents at an extremely hazardous location probably will far exceed the costs of any one treatment, it is reasoned that little can be lost and much can be gained by implementing the most effective treatment at that one location. However, where the engineer is considering implementation of delineation treatments on a state-wide or district-wide basis, the small cost differences between delineation treatments can result in significant total investment disparities. Thus, although this method of simply adopting the most effective treatment can be used for a particular location, it may not be applicable for use on a state-wide or district-wide basis.

Another approach is to use the measures of effectiveness to eliminate dominated treatments and thus reduce the set of treatments under consideration to a smaller set. One treatment dominates another if it costs no more and is more effective than the other. The analyst can then present the smaller set of treatments to the decision maker. (The decision maker may be a highway official or the engineer performing the analysis. For purposes of this discussion, a distinction is made between the two, even though the same individual may perform both functions.)

The engineer could also calculate effectiveness-to-cost ratios. The treatment that exhibits the highest effectiveness-to-cost ratio would be designated as "best." However, this approach is subject to the same difficulties as the benefit-to-cost ratio technique, as discussed in Appendix E. Another difficulty arises if more than one measure of effectiveness is used. In this case, some implicit weighting scheme must be developed that reduces these measures to a single measure of treatment effectiveness. Which treatment is deemed most acceptable will depend on the weighting scheme used. This approach can be formalized and structured to enhance its effectiveness. This is essentially the procedure suggested in Chapter Two, through the use of the Guideline Forms.

In the net benefit approach, the decision maker transforms the measures of effectiveness into dollar benefits and then subtracts the costs. The treatment that he believes will exhibit the highest net benefit is the one implemented. He assumes that some factor exists that relates the measures of effectiveness to dollar benefits. His assumption as to the magnitude of this factor will determine which treatment to implement, as is illustrated in the following discussion.

The factor, P, can be thought of as a price that includes both the correlation coefficient of the measures of effectiveness and accident rates, and the cost in dollars that transforms accident rates to dollar equivalent amounts.

Thus, if two treatments A_i and A_j are under consideration, with measured effectiveness levels of E_i and E_j, it can be assumed that a relation exists such that:

$$B_i = P\,E_i \qquad \text{(T-1)}$$

$$B_j = P\,E_j \qquad \text{(T-2)}$$

in which

B_i = dollar benefits for treatment A_i;
B_j = dollar benefits for treatment A_j;
E_i = measured effectiveness level of A_i; and
E_j = measured effectiveness level of A_j.

If the costs of the two treatments are at the levels C_i and C_j, and the net benefit of A_i is initially assumed to be greater than that of A_j,

$$B_i - C_i > B_j - C_j \qquad \text{(T-3)}$$

$$P\,E_i - C_i > P\,E_j - C_j \qquad \text{(T-4}a\text{)}$$

$$P(E_i - E_j) > C_i - C_j \qquad \text{(T-4}b\text{)}$$

$$P > \frac{C_i - C_j}{E_i - E_j} \text{ when } E_i - E_j > 0 \qquad \text{(T-5}a\text{)}$$

$$P < \frac{C_i - C_j}{E_i - E_j} \text{ when } E_i - E_j < 0 \qquad \text{(T-5}b\text{)}$$

Thus, only when P fulfills one of these conditions will the assumption that treatment A_i has a higher net benefit than A_j hold true. Alternative A_i can then be compared to all the other alternatives so as to establish the conditions on P that would make the net benefit of this treatment greater than all others. An example illustrates how this process may be used.

Assume that the engineer has under consideration five alternative delineation treatments with corresponding costs and effectiveness levels as follows:

TREATMENT	E	C
A_1	1	2
A_2	2	14
A_3	5	25
A_4	8	30
A_5	9	45

The measures of effectiveness can be in terms of relative reductions in erratic maneuvers or changes in intermediate criteria. If treatment A_5 has a higher net benefit than treatment A_4, it must be true that:

$$P E_5 - C_5 > P E_4 - C_4$$
$$P > \frac{C_5 - C_4}{E_5 - E_4} > \frac{45 - 30}{9 - 8} > 15. \quad \text{(T-6)}$$

That is, P must be greater than 15 for treatment A_5 to be better than treatment A_4. Treatment A_5 can then be compared to all the other alternatives in the same manner and the conditions on P that make A_5 better than all the other treatments can be established. The results are given in Table T-3, from which it can be seen that for treatment A_5 to be better than A_4, P must be greater than 15; for it to be better than treatment A_3, P must be greater than 5; and so forth for the other two alternatives. Thus, if treatment A_5 is the best alternative (i.e., if its net benefit is greater than any other alternative) P must be greater than 15. This type of analysis was carried out for all the alternatives under consideration; the results are given in Table T-3.

By scanning Table T-3, the engineer can establish the conditions on P that make each alternative better than all the others. Thus:

If A_5 is best: $P > 15$

If A_4 is best: $4 < P < 15$

If A_3 is best: $P > 5.75$, $P < 1.67$

If A_2 is best: $P > 12$, $P < 2.67$

If A_1 is best: $P < 4$

So, if $P > 15$, A_5 will be accepted as best. If $4 < P < 15$, A_4 will be accepted as best, and if $P < 4$, A_1 will be accepted as best. Treatments A_3 and A_2 can never exhibit the greatest net benefit, because conditions on P for both alternatives are inconsistent. That is, if A_3 is accepted as best, this implies that P must be greater than 5.75 and less than 1.67, which is, of course, impossible.

Although not explicitly determining the best treatment from the set, this analysis has reduced the number of treatments under consideration. The analyst can present treatments A_5, A_4, and A_1 to the decision maker, who can decide which treatment to implement on the basis of where he judges the actual value of P will fall. This procedure can add an additional measure of objectivity to the selection of delineation treatments on the basis of intermediate criteria and erratic maneuvers. If additional information is known, such as P can never be greater than 15 and never less than 4, this procedure clearly indicates that treatment A_4 should be implemented.

This procedure can be carried one step further if some probability distribution can be assumed for P. The analyst could calculate the expected ranking or the expected net benefit for each alternative using this distribution. This would add additional information that can be used in making delineation treatment judgments. It should also be noted that this whole procedure can be modified for use with benefit-cost ratios or rates of return. The analysis is the same except that instead of using net benefit as the criterion, one or the other of these criteria can be used.

This procedure can also be modified and used where more than one measure of effectiveness is present. If it is assumed that two treatments, A_i and A_j, are under consideration, each with corresponding measures of effectiveness and costs, and that treatment A_i is better than treatment A_j, Eq. T-3 holds true. However, the benefits of each treatment are obtained through the multiplication of the assumed prices and the measures of effectiveness. That is, if two measures of effectiveness, E_1 and E_2, are used with corresponding prices P_1 and P_2:

$$B_i = P_1 E_{1i} + P_2 E_{2i} \quad \text{(T-7)}$$

$$B_j = P_1 E_{1j} + P_2 E_{2j} \quad \text{(T-8)}$$

Then, if A_i is better than A_j,

$$P_1 E_{1i} + P_2 E_{2i} - C_i > P_1 E_{1j} + P_2 E_{2j} - C_j \quad \text{(T-9}a\text{)}$$

$$P_1(E_{1i} - E_{1j}) > (C_i - C_j) - P_2(E_{2i} - E_{2j}) \quad \text{(T-9}b\text{)}$$

$$P_1 > \frac{(C_i - C_j)}{(E_{1i} - E_{1j})} - P_2 \frac{(E_{2i} - E_{2j})}{(E_{1i} - E_{1j})} \; E_{1i} - E_{1j} > 0 \quad \text{(T-9}c\text{)}$$

$$P_1 < \frac{(C_i - C_j)}{(E_{1i} - E_{1j})} - P_2 \frac{(E_{2i} - E_{2j})}{(E_{1i} - E_{1j})} \; E_{1i} - E_{1j} < 0 \quad \text{(T-9}d\text{)}$$

Only under one of these conditions on P_1 and P_2 will treatment A_i exhibit a higher net benefit than treatment A_j. Rather than resulting in single numbers as in the previous example, the results are in terms of straight lines in two-dimensional space.

TABLE T-3

RELATIONSHIPS AMONG P-VALUES AND ALTERNATIVE TREATMENTS

If A_5 is best:	If A_4 is best:	If A_3 is best:
$A_5 > A_4 => P > 15$	$A_4 > A_5 => P < 15$	$A_3 > A_5 => P < 5$
$A_5 > A_3 => P > 5$	$A_4 > A_3 => P > 1.67$	$A_3 > A_4 => P < 1.67$
$A_5 > A_2 => P > 4.43$	$A_4 > A_2 => P > 2.67$	$A_3 > A_2 => P > 3.67$
$A_5 > A_1 => P > 5.375$	$A_4 > A_1 => P > 4$	$A_3 > A_1 => P > 5.75$

If A_2 is best:	If A_1 is best:
$A_2 > A_5 => P < 4.43$	$A_1 > A_5 => P < 5.375$
$A_2 > A_4 => P < 2.67$	$A_1 > A_4 => P < 4$
$A_2 > A_3 => P < 3.67$	$A_1 > A_3 => P < 5.75$
$A_2 > A_1 => P > 12$	$A_1 > A_2 => P < 12$

The engineer can compare the treatments for this case in the same manner as treatments were compared for the single effectiveness case. Ranges for the two prices can be obtained to indicate when preference switches from one alternative to another. Thus, as in the previous case, the number of alternative treatments to be considered can probably be reduced. The lines that are obtained by use of this procedure can be thought of as constraints in a linear programming problem. To eliminate a particular treatment, the analyst should solve the system to obtain inconsistent constraints. Any treatment whose constraints are inconsistent can never be accepted as best, and thus need not be considered further. This procedure is highly amenable to calculations using the electronic computer. If some joint probability distribution can be assumed for the two prices, the expected ranking or the expected net benefit for each treatment can be obtained. This will provide additional information that can be used by the decision maker in making delineation treatment judgments. It should be noted that this procedure can be used for any number of effectiveness measures; one additional dimension is added for each additional measure.

Expert Opinion

Expert opinion can be used to make delineation treatment judgments when no other data are available from either the accident records approach or the intermediate measures approach, or it can be used as a supplement to either of these techniques when certain parameters cannot be estimated quantitatively. It can also be used as a check on these two approaches to ensure reliable and consistent results. There are various ways that expert opinion can be used in making delineation treatment judgments. The engineer can draw on his own knowledge and experience, he can consult experts on an individual basis, or a group of experts can be consulted to help in making evaluations. When a group of experts is consulted, either the panel or the committee approach can be used or a diagnostic team can be used. Several methods for using the committee approach are presented in Appendix E. The diagnostic team approach is discussed at the beginning of this appendix.

The engineer can simply present any quantitative results concerning the various treatments to the experts and let them decide which treatment is most beneficial. Another approach is to attempt to formalize the intuitive notions of the experts so as to add a measure of objectivity to the subjective evaluation of delineation treatments. For example, the sources of information deficiencies can be given to the experts for their subjective appraisal of the relative importance of each. The experts can then rank each treatment as to how well it resolves each deficiency. Measures of effectiveness for each treatment can thus be obtained from expert opinion by noting how well each treatment resolves the information deficiencies. The Guideline Forms presented in Chapter Two are structured in this manner.

If used with discretion, expert opinion can be a great aid in the evaluation of treatment performance. It must be remembered, however, that the results were obtained from subjective evaluations and that no two groups of experts will always give the same evaluation.

APPENDIX U

FORMS

The forms used in the preparation of abstracts for the annotated bibliography, indexing of the articles to facilitate information retrieval, and current practices surveys are presented in this appendix. Also included are the response sheets used for the Coding Study (Appendix G) and the interview form used for the Positive/Negative Study (Appendix I).

Folder Number 99

Bk, Per, Soc Pub, Gov Pub, Manu (Circle One)

Matrix Classification: 2C

Author Schepp, A. J. and Lamb, D. R.

Affiliation Wyoming Hwy. Dept., Univ. of Wyoming

Title: "Shoulder Delineation Markings and Lateral Placement of Vehicles"

Publication, Vol, No., Date, Pages (Per) Public Works, Vol. 96, No. 4, pp. 118-20, April 1965

Edition, Plate, Publisher, Date, Pages (Books)

NOTES: (As summary, outline or quotes) Tests were conducted on four-lane divided highway in Wyoming to determine how different shoulder delineation markings effect the lateral placement of vehicles. The results show a shift of lateral placement toward the center line after dark for both passenger and commercial vehicles. Little difference in average lateral placement was observed over the study sites for the passenger vehicles during the daytime.

Dependent Variable lateral placement, encroachment

Independent Variable shoulder delineation type

Project: NCHRP 5-7

Abstracted by: HWM

Figure U-1. Final abstract form.

ARTICLE INDEX SHEET

AUTHOR: SCHEPP & LAMB

TITLE: SHOULDER DELINEATION MARKINGS AND LATERAL PLACEMENT OF VEHICLES

NO. ______

SITUATION \ TREATMENT	A. GENERAL	B. COLOR PAVEMENTS	C. PAVEMENT MARKING	D. RAISED DELINEATORS	E. POST DELINEATORS	F. SIGNS	G. CURBS	H. RUMBLE STRIPS	I. INDIRECT METHODS	J. SYSTEMS	a. HUMAN FACTORS	b. TRAFFIC CHARACTER	c. COSTS	d. ACCIDENTS	e. MATERIALS	f. MAINTENANCE	g. ENVIRONMENT EFFECTS	h. COLOR CODING	i. CURRENT USAGE	j. THEORY & EXPER.	k. NEW IDEAS & MAT'L.	l. METHODOLOGY
1. GENERAL			X									X										X
2. TANGENTS			X									X										X
3. CURVES (HORIZ)																						
4. CURVES (VERT)																						
5. WIDTH TRANS																						
6. TURNS																						
7. EXIT RAMP																						
8. ENTRANCE RAMP																						
9. CROSS WALKS																						
10. R.R. APPROACHES																						
11. OBSTRUCTIONS																						
12. PULL-OFFS																						
13. PASSING LANES																						
14. CROSSING & WEAVING																						
15. MERGING & DIVERGING																						
16. REVERSIBLE LANES																						
17. CUMBING LANES																						
A. HUMAN FACTORS																						
B. TRAFFIC CHARACTER			X																			
C. COSTS																						
D. ACCIDENTS																						
E. MATERIALS																						
F. MAINTENANCE																						
G. ENVIRONMENT																						
H. COLOR CODING																						
I. CURRENT USAGE																						
J. THEORY & EXPER																						
K. NEW IDEAS & MAT'LS																						
L. METHODOLOGY			X																			

Figure U-2. Article index sheet.

Part I

I. Relating to MUTCD (Manual Uniform Traffic Control Devices)

1. Do you feel there is any need to up date the MUTCD?

2. If the Manual for Uniform Traffic Control Devices were to be revised, what areas in regards to delineation would you like to see deleted, added, or modified?

3. Do you feel the warrants for delineation are specific enough? If not, at what level of specificity would you prefer?

II. Relating to State's Current Practices

Note: Might consider following the current practice questionnaire and ask questions on each treatment.

1. Introduce questions on any observations we made previous to interview, while driving on the state's highways.

2. Aside from painted lines and post delineators, such as color pavement or raised lane markers, do you use any special delineation treatments?

3. Within your state are there any situations requiring some form of delineation which are of particular problem in the form of accidents and/or traffic flow? What type of treatment did you apply to these situations? Was the treatment a success or failure and in what regards (i.e., accident reduction, high benefit-cost ratio) was it so?

III. Research and Experience

1. Have you conducted any research in the area of delineation? Have the results of this research been published?

2. Have you conducted any spot-studies or minor-improvement programs involving delineation? What were your findings?

3. Would it be possible to obtain copies of your intra-department correspondence, department memos, etc. which are concerned with delineation research and applications.

4. What is your practical experience with the various materials available for delineation?

   Do you have any particular maintenance problems?

IV. General Questions

1. Where does principal responsibility of delineation lie within the state?

   --Local vs. state control
   --Where within state highway department

2. How do you view delineation in the overall view of traffic control devices?

3. Do you consider delineation as a means of reducing accident probabilities?

   --Have you had any experience where accidents have been reduced because of improved delineation?

4. Do you consider delineation more as traffic flow aid or as an accident reducer?

5. How would you rank the following items when considering delineation treatment?

   1) Effectiveness as a traffic flow aid
   2) Effectiveness as an accident reducer
   3) Cost
   4) Maintenance
   5) Aesthetics
   6) Other

6. Are there any questions that you as a traffic engineer would want answered regarding delineation?

7. Are you aware of any inconsistencies between the vehicle code and delineation practices?

8. Do you consider our format for presenting our findings usable? Do you have any recommendations for change? (Show proposed and alternate formats.)

Part II

Listed below is the type of structure we intend to employ in providing delineation information for the practicing traffic engineer. Do you feel this type of format is usable?

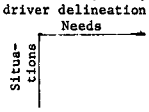
Format

It will not be possible within the scope of this project to develop an "installation" manual which can be taken directly to the field. It will be necessary for a traffic engineer to interpret the guidelines furnished in the project manual and fit them to the specifics of his situation, including any state-specific restraints.

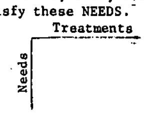
It is far more likely that the state highway and traffic engineers will utilize the manual in situation-specific terms -- i.e., they will turn to the manual when they have a specific curve intersection, etc. or a new section of road to delineate.

Given these conditions the format will be:

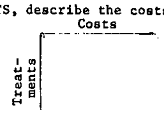
1. For each delineation SITUATION, i.e., tangent, horizontal curve, exit ramp, describe the driver delineation requirements -- NEEDS



2. Given the driver delineation requirements or NEEDS recommend one or more delineation TREATMENTS, i.e., red color pavements, blue post delineators, to satisfy these NEEDS.



3. Given the TREATMENTS, describe the costs involved for each treatment.



4. Apply formula to determine the most effective treatment or delineation system for the specific situation of interest which is flexible enough to incorporate local environmental conditions, local treatment costs, state-specific delineation policies, etc.

Alternate Format

1. Describe SITUATION, e.g., FREEWAY EXIT RAMP

2. Propose treatments in order of effectiveness with costs.

   e.g.

Effectiveness	Treatment	
High	1. Sign ($) + Edge Line ($) + Post Delineator ($) + Edge Rumble Strip ($)	Total $
	2. Sign ($) + Colored Pavement ($)	Total $
	3. Sign ($) + Post Delineator ($) + Edge Line ($)	Total $
	4. Sign ($) + Flashing Curb Lights ($)	Total $
	5. Sign ($) + Edge Line ($)	Total $
Low	6. Sign ($) + Post Delineator ($)	Total $

Figure U-3. Current practices interview.

FORM 4-RESPONSE SHEETS FOR CODING STUDY-PART 1 (APPENDIX G)

RESPONSE SHEET - PART 1 - 1

1.	___Turn Slot	___Right Curve	___Roadway Obstruction	___Right Lane Drop	___Stop Approach
2.	___Left Curve	___Bridge	___S-Curve	___Exit Ramp	___Right Curve
3.	___Right Lane Drop	___Left Curve	___Turn Slot	___Exit Ramp	___Entrance Ramp
4.	___Right Curve	___S-Curve	___Exit Ramp	___Stop Approach	___Bridge
5.	___Right Lane Drop	___Left Curve	___Roadway Obstruction	___Exit Ramp	___Railroad Crossing
6.	___Entrance Ramp	___Diverge Main-stream	___Right Lane Drop	___Exit Ramp	___Right Curve
7.	___Bridge	___Left Curve	___Entrance Ramp	___Two-Way Tangent	___Right Lane Drop
8.	___Roadway Obstruction	___Right Curve	___Railroad Crossing	___Left Curve	___Entrance Ramp
9.	___Exit Ramp	___Entrance Ramp	___Right Curve	___Left Lane Drop	___Bridge
10.	___S-Curve	___Bridge	___Stop Approach	___No-Passing Zone	___Left Curve
11.	___Right Curve	___Diverge Main-stream	___Exit Ramp	___Stop Approach	___Wrong Way
12.	___Roadway Obstruction	___Two-Way Tangent	___Left Curve	___Right Curve	___Left Lane Drop
13.	___Left Lane Drop	___Right Curve	___Left Curve	___Turn Slot	___Stop Approach
14.	___Right Curve	___Bridge	___S-Curve	___Left Curve	___Exit Ramp
15.	___Exit Ramp	___Right Curve	___Railroad Crossing	___Turn Slot	___Left Lane Drop
16.	___Left Curve	___Exit Ramp	___Entrance Ramp	___Right Lane Drop	___Turn Slot
17.	___Exit Ramp	___Diverge Main-stream	___Right Curve	___Entrance Ramp	___No-Passing Zone
18.	___Tangent	___Stop Approach	___Wrong Way	___No-Passing Zone	___Entrance Ramp
19.	___Wrong Way	___Diverge Main-stream	___Left Lane Drop	___Tangent	___Stop Approach
20.	___Wrong Way	___Stop Approach	___Roadway Obstruction	___Tangent	___Left Lane Drop

Figure U-4. Response sheets for coding study—Part 1 (Appendix G).

FORM 4 (CONTINUED)

RESPONSE SHEET - PART 1 - 2

21.	___Roadway Obstruction	___Left Curve	___Stop Approach	___Right Curve	___Exit Ramp
22.	___Bridge	___Crossover	___Turn Slot	___Right Lane Drop	___Left Curve
23.	___Exit Ramp	___Bridge	___Right Curve	___Entrance Ramp	___Left Lane Drop
24.	___Tangent	___Wrong Way	___Roadway Obstruction	___Stop Approach	___Turn Slot
25.	___Right Curve	___Entrance Ramp	___Diverge Mainstream	___Exit Ramp	___Tangent
26.	___Exit Ramp	___Right Curve	___Entrance Ramp	___Bridge	___Left Lane Drop
27.	___No-Passing Zone	___Right Curve	___Tangent	___Bridge	___Tangent
28.	___Turn Slot	___Crossover	___Left Curve	___Exit Ramp	___Right Curve
29.	___Right Curve	___Roadway Obstruction	___Stop Approach	___Left Curve	___Entrance Ramp
30.	___Railroad Crossing	___No-Passing Zone	___Bridge	___Left Curve	___Roadway Obstruction
31.	___Left Lane Drop	___Stop Approach	___Exit Ramp	___Crossover	___Right Curve
32.	___Right Curve	___Entrance Ramp	___Exit Ramp	___Roadway Obstruction	___Diverge Mainstream
33.	___Crossover	___Intersection	___Exit Ramp	___Right Curve	___Tangent
34.	___Turn Slot	___Exit Ramp	___Right Lane Drop	___Roadway Obstruction	___Right Curve
35.	___Diverge Mainstream	___Roadway Obstruction	___Exit Ramp	___Entrance Ramp	___Right Curve
36.	___Entrance Ramp	___Tangent	___Left Curve	___Railroad Crossing	___Right Curve
37.	___Right Lane Drop	___Left Curve	___Exit Ramp	___No-Passing Zone	___Stop Approach
38.	___Exit Ramp	___Crossover	___S-Curve	___Right Curve	___Merge Mainstream
39.	___Roadway Obstruction	___Right Lane Drop	___Railroad Crossing	___Right Curve	___Crossover
40.	___Stop Approach	___Left Lane Drop	___Entrance Ramp	___Right Curve	___Exit Ramp

FORM 4 (CONTINUED)

RESPONSE SHEET - PART 1 - 3

41.	___Left Curve	___Right Curve	___Roadway Obstruction	___Exit Ramp	___Crossover
42.	___Left Lane Drop	___Left Curve	___Right Curve	___Right Lane Drop	___Stop Approach
43.	___Bridge	___Right Lane Drop	___Left Curve	___S-Curve	___Crossover
44.	___Roadway Obstruction	___Wrong Way	___Tangent	___Left Curve	___Stop Approach
45.	___Merge Mainstream	___Right Curve	___Turn Slot	___Crossover	___Exit Ramp
46.	___Stop Approach	___Left Lane Drop	___Right Curve	___Turn Slot	___Crossover
47.	___Left Lane Drop	___Railroad Crossing	___Left Turn	___Exit Ramp	___Crossover
48.	___Left Turn	___Roadway Obstruction	___Diverge Mainstream	___Exit Ramp	___Tangent
49.	___Diverge Mainstream	___Right Curve	___Crossover	___Entrance Ramp	___Exit Ramp
50.	___Right Curve	___Turn Slot	___Exit Ramp	___Roadway Obstruction	___Left Lane Drop
51.	___S-Curve	___Right Curve	___Left Lane Drop	___Exit Ramp	___Left Curve
52.	___Railroad Crossing	___Tangent	___Stop Approach	___Turn Slot	___Bridge
53.	___Left Curve	___Diverge Mainstream	___Merge Main-stream	___Entrance Ramp	___Right Lane Drop
54.	___Tangent	___Right Curve	___Diverge Mainstream	___Stop Approach	___Entrance Ramp
55.	___Stop Approach	___Bridge	___Right Lane Drop	___Roadway Obstruction	___Merge Mainstream
56.	___Wrong Way	___Stop Approach	___Left Turn	___Exit Ramp	___Crossover
57.	___Entrance Ramp	___Left Curve	___Bridge	___Turn Slot	___Stop Approach
58.	___Exit Ramp	___Tangent	___Right Lane Drop	___Right Curve	___Crossover
59.	___Entrance Ramp	___Crossover	___Left Turn	___Stop Approach	___Roadway Obstruction
60.	___Tangent	___Exit Ramp	___Entrance Ramp	___Roadway Obstruction	___Merge Main-stream

FORM 4 (CONTINUED)

RESPONSE SHEET - PART 1 - 4

61.	___Exit Ramp	___Cattle Crossing	___Merge Mainstream	___Railroad Crossing	___Right Curve
62.	___Stop Approach	___Tangent	___Wrong Way	___Turn Slot	___Roadway Obstruction
63.	___Wrong Way	___Merge Mainstream	___Roadway Obstruction	___Right Curve	___Right Lane Drop
64.	___Tangent	___Bridge	___Right Curve	___Crossover	___Left Lane Drop
65.	___Stop Approach	___Left Lane Drop	___Roadway Obstruction	___Crossover	___Airstrip
66.	___Diverge Mainstream	___Right Curve	___Entrance Ramp	___Exit Ramp	___Railroad Crossing
67.	___Right Curve	___Exit Ramp	___Tangent	___Left Lane Drop	___Crossover
68.	___Diverge Mainstream	___Left Curve	___Turn Slot	___Entrance Ramp	___Right Lane Drop
69.	___Turn Slot	___Crossover	___Exit Ramp	___Right Curve	___Left Curve
70.	___Right Turn	___Tangent	___Stop Approach	___Intersection	___Crossover
71.	___Roadway Obstruction	___Tangent	___Wrong Way	___Stop Approach	___Right Lane Drop
72.	___Crossover	___Stop Approach	___Entrance Ramp	___Exit Ramp	___Bridge
73.	___Diverge Mainstream	___Left Lane Drop	___Exit Ramp	___Right Curve	___Left Curve
74.	___Right Lane Drop	___Tangent	___Stop Approach	___Crossover	___Exit Ramp
75.	___Exit Ramp	___S-Curve	___Right Curve	___Tangent	___Left Curve
76.	___Right Curve	___Exit Ramp	___Right Lane Drop	___Stop Approach	___Crossover
77.	___Entrance Ramp	___Crossover	___Exit Ramp	___Left Lane Drop	___S-Curve
78.	___Tangent	___Stop Approach	___Turn Slot	___Left Curve	___Exit Ramp
79.	___Diverge Mainstream	___Right Lane Drop	___Exit Ramp	___Left Curve	___Entrance Ramp
80.	___Turn Slot	___Right Lane Drop	___Entrance Ramp	___Roadway Obstruction	___Exit Ramp

FORM 4 (CONTINUED)

RESPONSE SHEET - PART 1 - 5

81.	___Crossover	___Right Lane Drop	___Exit Ramp	___Left Curve	___Right Curve
82.	___Tangent	___Right Lane Drop	___Stop Approach	___Roadway Obstruction	___Entrance Ramp
83.	___Tangent	___Entrance Ramp	___Crossover	___Stop Approach	___Left Curve
84.	___Exit Ramp	___Right Curve	___Left Curve	___Right Lane Drop	___S-Curve
85.	___Right Curve	___Left Curve	___Exit Ramp	___Left Lane Drop	___Crossover
86.	___Entrance Ramp	___Merge Mainstream	___Left Curve	___Right Lane Drop	___Crossover
87.	___Tangent	___No-Passing Zone	___Railroad Crossing	___Right Curve	___Left Curve
88.	___Left Lane Drop	___Left Curve	___Right Lane Drop	___Tangent	___Roadway Obstruction
89.	___Left Lane Drop	___Entrance Ramp	___Right Curve	___Exit Ramp	___Tangent
90.	___Diverge Mainstream	___Right Curve	___Entrance Ramp	___Left Lane Drop	___Exit Ramp
91.	___Exit Ramp	___Roadway Obstruction	___Left Lane Drop	___Right Curve	___Entrance Ramp
92.	___Right Lane Drop	___Left Curve	___Tangent	___Right Curve	___Stop Approach
93.	___Left Curve	___S-Curve	___Right Curve	___No-Passing Zone	___Left Lane Drop
94.	___Roadway Obstruction	___Right Curve	___Entrance Ramp	___Left Lane Drop	___Exit Ramp
95.	___Roadway Obstruction	___Tangent	___Right Lane Drop	___Wrong Way	___Stop Approach
96.	___Exit Ramp	___Crossroad	___Right Curve	___Entrance Ramp	___Merge Mainstream
97.	___Right Curve	___Tangent	___Stop Approach	___Roadway Obstruction	___Left Curve
98.	___Left Lane Drop	___Right Lane Drop	___Turn Slot	___Left Curve	___Roadway Obstruction
99.	___S-Curve	___Wrong Way	___Railroad Crossing	___Right Lane Drop	___Stop Approach
100.	___Exit Ramp	___No-Passing Zone	___Roadway Obstruction	___Right Curve	___Left Lane Drop

FORM 4 (CONTINUED)

RESPONSE SHEET - PART 1 - 6

101.	___Right Curve	___Left Lane Drop	___Exit Ramp	___Tangent	___Crossroad
102.	___Entrance Ramp	___Left Curve	___Turn Slot	___Roadway Obstruction	___Right Lane Drop
103.	___Tangent	___Stop Approach	___Left Lane Drop	___Wrong Way	___Roadway Obstruction
104.	___Entrance Ramp	___Tangent	___Left Curve	___Right Lane Drop	___No-Passing Zone
105.	___Exit Ramp	___Merge Mainstream	___Entrance Ramp	___Turn Slot	___Tangent
106.	___Roadway Obstruction	___Right Curve	___Stop Approach	___Tangent	___Entrance Ramp
107.	___Left Curve	___Tangent	___Roadway Obstruction	___Right Curve	___Left Lane Drop
108.	___Roadway Obstruction	___Left Lane Drop	___Right Curve	___Exit Ramp	___Entrance Ramp
109.	___Diverge Mainstream	___Entrance Ramp	___Exit Ramp	___Left Lane Drop	___Tangent
110.	___No-Passing Zone	___Left Curve	___Stop Approach	___Right Curve	___Tangent
111.	___Right Lane Drop	___Tangent	___Stop Approach	___Left Curve	___No-Passing Zone
112.	___Entrance Ramp	___Left Lane Drop	___Right Curve	___Diverge Mainstream	___Exit Ramp
113.	___Exit Ramp	___Turn Slot	___Crossroad	___Left Lane Drop	___Right Curve
114.	___Tangent	___Left Lane Drop	___S-Curve	___Roadway Obstruction	___Right Curve
115.	___Left Lane Drop	___Right Curve	___Left Curve	___Wrong Way	___Roadway Obstruction
116.	___Right Curve	___Diverge Mainstream	___Entrance Ramp	___Exit Ramp	___Left Lane Drop
117.	___Right Curve	___Tangent	___Stop Approach	___Left Curve	___Right Lane Drop
118.	___Left Lane Drop	___Left Curve	___Roadway Obstruction	___Right Lane Drop	___Tangent
119.	___Crossroad	___No-Passing Zone	___Right Curve	___Left Curve	___Exit Ramp
120.	___Tangent	___Roadway Obstruction	___Bridge	___Left Curve	___Right Curve

Situation	Color	Treatment	Location
1. Roadway Obstruction	1. Yellow/Amber	1. Reflective Buttons (Guardrail or Fence)	1. Lane Line
2. Two-Way - Tangent	2. White/Clear	2. Paint	2. Shoulder
3. Right Curve	3. Red	3. Pavement Arrows	3. Shoulder Edge-line
4. Turn Slot	4. Purple	4. Channelizing Islands	4. Crosswalk
5. Left Curve	5. Blue	5. Contrasting Pavement	5. Ramp
6. Divided Half - Tangent		6. Post Mounted Reflectors	6. Pavement Width Transition
7. No-Passing Zone		7. Reflective Raised Pavement Markers	7. Gore
8. S-Curve			8. Outside of Curve
9. Diverge - Mainstream			9. Speed Change Lane
10. Stop Approach			10. Taper
11. Exit Ramp			11. Crossroad
12. Merge - Mainstream			12. Median Edge Line
13. Entrance Ramp			13. Inside of Curve
14. Bridge			14. Center Line
15. Left Taper Lane Drop			
16. Right Taper Lane Drop			
17. Railroad Crossing			
1. ___	1. ___ ___ ___	1. ___ ___ ___	1. ___ ___ ___
2. ___	2. ___ ___ ___	2. ___ ___ ___	2. ___ ___ ___
3. ___	3. ___ ___ ___	3. ___ ___ ___	3. ___ ___ ___
4. ___	4. ___ ___ ___	4. ___ ___ ___	4. ___ ___ ___
5. ___	5. ___ ___ ___	5. ___ ___ ___	5. ___ ___ ___

RESPONSE SHEET - PART 2 - B

Situation	Treatment	Color	Location
1. Stop Approach	1. Paint	1. Blue	1. Inside of Curve
2. Right Curve	2. Contrasting Pavement	2. White/Clear	2. Center Line
3. Right Taper Lane Drop	3. Reflective Buttons (Guardrail or Fence)	3. Purple	3. Outside of Curve
4. Left Curve	4. Channelizing Islands	4. Red	4. Pavement Width Transition
5. Bridge	5. Pavement Arrows	5. Yellow/Amber	5. Shoulder Edge Line
6. No-Passing Zone	6. Reflective Raised Pavement Markers		6. Ramp
7. Railroad Crossing	7. Post Mounted Reflectors		7. Crossroad
8. S-Curve			8. Shoulder
9. Roadway Obstruction			9. Taper
10. Entrance Ramp			10. Gore
11. Left Taper Lane Drop			11. Lane Line
12. Turn Slot			12. Median Edge Line
13. Two-Way - Tangent			13. Crosswalk
14. Divided Half - Tangent			14. Speed Change Lane
15. Merge - Mainstream			
16. Exit Ramp			
17. Diverge - Mainstream			
1. ___	1. ___ ___ ___	1. ___ ___ ___	1. ___ ___ ___
2. ___	2. ___ ___ ___	2. ___ ___ ___	2. ___ ___ ___
3. ___	3. ___ ___ ___	3. ___ ___ ___	3. ___ ___ ___
4. ___	4. ___ ___ ___	4. ___ ___ ___	4. ___ ___ ___
5. ___	5. ___ ___ ___	5. ___ ___ ___	5. ___ ___ ___

Figure U-5. Response sheets for coding study—Part 2 (Appendix G).

RESPONSE SHEET - PART 2 - C

Situation

1. Merge - Main-stream
2. Left Taper Lane Drop
3. Diverge - Main-stream
4. Stop Approach
5. Turn Slot
6. Exit Ramp
7. S-Curve
8. Entrance Ramp
9. Railroad Crossing
10. Divided Half - Tangent
11. Right Curve
12. Bridge
13. Right Taper Lane Drop
14. Left Curve
15. Roadway Ob-struction
16. Two-Way - Tangent
17. No-Passing Zone

Treatment

1. Channelizing Islands
2. Contrasting Pavement
3. Pavement Arrows
4. Reflective Raised Pavement Markers
5. Reflective Buttons (Guardrail or Fence)
6. Post Mounted Reflectors
7. Paint

Color

1. Red
2. Yellow/Amber
3. Purple
4. Blue
5. White/Clear

Location

1. Speed Change Lane
2. Ramp
3. Outside of Curve
4. Shoulder Edge Line
5. Shoulder
6. Median Edge Line
7. Gore
8. Pavement Width Transition
9. Crosswalk
10. Lane Line
11. Taper
12. Inside of Curve
13. Center Line
14. Crossroad

Situation	Treatment	Color	Location
1. ___	1. ___ ___ ___	1. ___ ___ ___	1. ___ ___ ___
2. ___	2. ___ ___ ___	2. ___ ___ ___	2. ___ ___ ___
3. ___	3. ___ ___ ___	3. ___ ___ ___	3. ___ ___ ___
4. ___	4. ___ ___ ___	4. ___ ___ ___	4. ___ ___ ___
5. ___	5. ___ ___ ___	5. ___ ___ ___	5. ___ ___ ___

RESPONSE SHEET - PART 2 - D

Situation

1. Entrance Ramp
2. Railroad Crossing
3. Right Taper Lane Drop
4. Diverge - Main-stream
5. Left Curve
6. Roadway Ob-struction
7. Stop Approach
8. Left Taper Lane Drop
9. Divided Half - Tangent
10. S-Curve
11. Bridge
12. Two-Way - Tangent
13. Right Curve
14. Turn Slot
15. Exit Ramp
16. Merge - Main-stream
17. No-Passing Zone

Treatment

1. Contrasting Pavement
2. Reflective Raised Pavement Markers
3. Pavement Arrows
4. Paint
5. Post Mounted Reflectors
6. Reflective Buttons (Guardrail or Fence)
7. Channelizing Islands

Location

1. Speed Change Lane
2. Shoulder
3. Pavement Width Transition
4. Median Edge Line
5. Lane Line
6. Crossroad
7. Taper
8. Shoulder Edge Line
9. Crosswalk
10. Outside of Curve
11. Gore
12. Ramp
13. Inside of Curve
14. Center Line

Color

1. White/Clear
2. Blue
3. Purple
4. Red
5. Yellow/Amber

Situation	Treatment	Location	Color
1. ___	1. ___ ___ ___	1. ___ ___ ___	1. ___ ___ ___
2. ___	2. ___ ___ ___	2. ___ ___ ___	2. ___ ___ ___
3. ___	3. ___ ___ ___	3. ___ ___ ___	3. ___ ___ ___
4. ___	4. ___ ___ ___	4. ___ ___ ___	4. ___ ___ ___
5. ___	5. ___ ___ ___	5. ___ ___ ___	5. ___ ___ ___

RESPONSE SHEET - PART 2 - E

Situation	Color	Location	Treatment
1. No-Passing Zone	1. Blue	1. Outside of Curve	1. Reflective Buttons (Guardrail or Fence)
2. Roadway Obstruction	2. Purple	2. Center Line	2. Pavement Arrows
3. Divided Half - Tangent	3. Red	3. Gore	3. Reflective Raised Pavement Markers
4. Turn Slot	4. White/Clear	4. Lane Line	4. Post Mounted Reflectors
5. Entrance Ramp	5. Yellow/Amber	5. Crosswalk	5. Paint
6. Left Curve		6. Shoulder Edge Line	6. Contrasting Pavement
7. Right Taper Lane Drop		7. Ramp	7. Channelizing Islands
8. S-Curve		8. Median Edge Line	
9. Merge - Mainstream		9. Pavement Width Transition	
10. Right Curve		10. Taper	
11. Two-Way Tangent		11. Inside of Curve	
12. Stop Approach		12. Crossroad	
13. Exit Ramp		13. Shoulder	
14. Bridge		14. Speed Change Lane	
15. Railroad Crossing			
16. Diverge - Mainstream			
17. Left Taper Lane Drop			
1. ___	1. ___ ___ ___	1. ___ ___ ___	1. ___ ___ ___
2. ___	2. ___ ___ ___	2. ___ ___ ___	2. ___ ___ ___
3. ___	3. ___ ___ ___	3. ___ ___ ___	3. ___ ___ ___
4. ___	4. ___ ___ ___	4. ___ ___ ___	4. ___ ___ ___
5. ___	5. ___ ___ ___	5. ___ ___ ___	5. ___ ___ ___

1. Is there anything about the roadway or vehicle which you wish to comment upon?
2. Did you notice differences between any of the runs? If yes, describe the difference and specify on which run you noticed it.
3. Did you notice a change in the size of any of the reflective markers? On which run?
4. Did you notice any differences in the brightness of the post delineators from run to run. At what location? On which run?
5. Did you notice any color differences between the various runs? Which runs?
6. If you see amber post delineators on the roadside, at other than interchange ramps, what does this mean to you?
7. Have amber post delineators on the roadside ever caused you to be confused? How?
8. Have you ever been faced with an emergency situation which required you to leave the roadway?
9. How long have you been driving? Approximately how many miles per year do you typically drive?

Figure U-6. Subject interview form, positive vs positive/negative study (Appendix I).

APPENDIX V

BIBLIOGRAPHY

The review of the past and current research uncovered a large volume of literature pertaining to roadway delineation, the driving task, cost effectiveness, and other related research. With few exceptions all the literature included in the bibliography is referenced in this report.

The bibliography is divided into nine sections closely patterned after the state of the art, Appendices A through E, as follows:

1. Delineation applications.
2. Delineation materials.
3. Practices in other countries.
4. Human factors—general.
5. Visual perception.
6. Information processing.
7. Cost effectiveness—general methodology.
8. Cost effectiveness—highway improvement projects.
9. Miscellaneous.

Each section begins with a few annotations of references that serve as a cross section of that category. The remainder of the references are entered by title and source only. Both the annotations and the titles are in alphabetical order by author or agency.

DELINEATION APPLICATIONS

1. ANDERSON, J. W., and PEDERSON, V. L., "The Effect of Color in Guidance of Traffic at Interchanges." Investigation No. 318, Traffic Engineering Section, Minnesota Dept. Highways (1963) (unpublished).

   The report describes a study designed to evaluate the use of color systems in guiding traffic through highway interchanges. The study was conducted on an Interstate cloverleaf interchange and used 12-in.-wide reflectorized colored edge lines, colored post delineators, and colored guide signs. Both blue and yellow colors were intermixed on various exits and entrances. Before-and-after studies were made to determine changes in driver performance, and a driver interview was used to determine driver awareness of color treatments. Results indicated that blue exits had higher exit speeds and later point of exit, while yellow exits had slower exit speeds and earlier point of exit. Only 25 percent of the drivers interviewed indicated an awareness of the various color treatments.

2. BASILE, A. J., "Effect of Pavement Edge Markings on Traffic Accidents in Kansas." *HRB Bull. 308* (1962) pp. 80-86.

   The Kansas State Highway Commission in 1960 conducted a study to determine what effect pavement edge markings on two-lane roads may have on accident rates. A controlled type of before-and-after accident comparison study was selected for the survey. The significant conclusions from their study were: (1) on two-lane rural state highways the use of pavement edge markings resulted in a reduction in the number of fatalities; (2) there was no significant change in the number of persons injured or in the total number of accidents; (3) accidents at intersections and driveways were significantly reduced under both daytime and nighttime conditions.

3. CONLEY, C. F., and ROTH, W. J., *Interchange Ramp, Color Delineation, and Marking Study: Erratic Movement Survey Report.* U.S. Dept. of Transportation (Dec. 1967).

   This study was an attempt to classify and, at least to a limited degree, validate erratic movements as intermediate criteria in the evaluation of driver performance under specific test treatments. Described were five distinct classes of erratic movements: (1) delayed exit—a vehicle crossing the painted gore of an exit; (2) false exit—a vehicle beginning an exit and returning to through lane; (3) backing at gore—a vehicle stopping beyond the gore and backing up either on the through roadway or on the ramp in order to change directions; (4) rapid deceleration or swerve on correct path—a vehicle following his intended path, but taking an abrupt action to do so; (5) stop or slow—a vehicle coming to a complete stop to decide which way to go or is definitely confused and slows down.

4. DART, O. K., JR., "A Study of Roadside Delineator Effectiveness On an Interstate Highway." *Hwy. Res. Record No. 105* (1965) pp. 21-49.

   This study reports on the effectiveness of post-mounted roadside delineators as a traffic control device. Speed and lateral placement measurements were taken for several conditions of delineation type (no delineators, post-mounted delineators, or shoulder stripes); roadway alignment (straight or curved); day, night, or twilight; travel direction; vehicle. Neither post-mounted delineators nor shoulder stripes were shown to have any significant effect on the dependent variables; however, drivers were almost unanimous in their feeling that roadside delineation is helpful. Mean speeds for nondelineated conditions were significantly higher than speeds for either type of delineation. Placements were closer to the center line during the night and closer to the center line on curves.

5. GWYNN, D. W., and SEIFERT, J., "Red Colored Pavement." *Hwy. Res. Record No. 221* (1968) pp. 15-22.

   A before-and-after study was performed on a ramp ending with a STOP sign and at the ramp's intersection with a one-way roadway. Speeds and lags for both day and night conditions were measured before and after the ramp was paved red. Ramp traffic stopping and ramp and highway traffic crossing the intersection were manually recorded using a 20-pen recorder. Average accepted and rejected lags were computed. Before and after measurements were compared: the daytime speeds were significantly lower after the ramp was paved red, but for nighttime speeds and daytime and nighttime lags, there were no significant differences. (Author)

6. HALVERSON, J. R., "Right Shoulder Guide Lines." *Traffic Safety,* Vol. 57, No. 3 (Sept. 1957) pp. 20-22, 32.

   The article reports on Utah's early (1957) experience with right-shoulder guide lines, which had reduced three of the most prevalent types of accidents: head-on collisions, sideswipes (overtaking), and running off the roadway. Guide lines also affected the lateral placement of passenger and commercial vehicles.

7. KERMIT, M. L., "Rumble Strips Revisited." *Traffic Eng.,* Vol. 38, No. 5 (Feb. 1968) pp. 26-30.

   The article describes the use of transverse rumble strips in advance of a dangerous T-intersection. During the first experiment in 1962, accidents were reduced by 50 percent with the emplacement of the rumble strips. When the road was repaved and the rumble strips were not placed back, accidents increased again. This experience has reaffirmed the efficacy of rumble strips.

8. LONGENECKER, K. E., *Evaluation of Minor Improvements: Part 1. Delineation.* Idaho Dept. of Highways.

   This investigation analyzed and evaluated the effectiveness of reflectorized delineation markers in reducing reported accidents in 47 delineation projects on 559 miles of two-lane primary and secondary routes in Idaho. A before-and-after study methodology was used for evaluation. The results of the study indicate that reflectorized delineation has the greatest beneficial effect on night accidents at curves.

9. Missouri State Highway Commission, *Some Effects of Pavement Edge Lines on Driver Behavior.* Res. Rep. 69-10 (Dec. 1969).

   The objective of this study was to determine some of the effects of edge-line striping on driver behavior. This was accomplished through an analysis of lateral vehicular placement, vehicular speeds, and driver comfort. In evaluating these effects, measurements of these variables were made before and after placing edge lines on designated test sections. These sections were established on rural, two-way highways that had varying traffic volumes, surface types, and roadway widths.

   Results indicate that vehicles generally tend to move closer to the center line of the pavement during free-moving traffic conditions (no interference from other vehicles) after application of a 4-in. edge line. Edge lines had no significant effect on average vehicular speeds. The results of the galvanic skin response analyses were inconclusive in providing a significant increase in driver comfort after edge lining.

10. MUSICK, J. V., "Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio." *HRB Bull. 266* (1966) pp. 1-7.

    This paper discusses an experiment conducted on the effectiveness of pavement edge markings for two-lane rural highways in Ohio (1956-57). The use of pavement edge markings led to the following conclusions: (1) There was a significant reduction in fatality and injury-causing accidents. (2) Accidents at intersections, alleys, and driveways were significantly reduced but accidents between access points showed no significant change. (3) The only type of collision to show a significant reduction was the angle collision associated with access points. (4) There was no significant change in day accidents; night accidents were reduced, but the change was marginal as far as statistical significance is concerned.

11. Oregon State Highway Department, *Color Coded Interchange Ramps.* (Jan. 1966).

    This study was conducted to determine the value of using a color-coding system to aid drivers in making a quick identification of freeway exit locations at night. Using a before-and-after type of procedure, speed and lateral placement for passenger vehicles were measured. The findings were that color coding (1) resulted in a smoother exit path, (2) seemed to be most effective on ramps having the greatest distance between the beginning of deceleration lane and the gore point, (3) has no effect on the speeds of exiting vehicles, (4) had no definite effect on accidents, and (5) seemed to be most applicable to special problem areas.

12. OWENS, R. D., "Effect of Rumble Strips at Rural Stop Locations on Traffic Operation." *Hwy. Res. Record No. 170* (1967) pp. 35-55.

    This study investigated the effect of rumble strips on traffic operation and behavior. The purpose of this study was to analyze a traffic control device that was expected to additionally alert drivers to the necessity of deceleration at rural stop locations and thereby cause safer operation at these locations. The major goals were to (1) effect a reduction in average approach speeds; (2) increase the observance of the STOP sign controls; and (3) decrease the number of accidents involving approaching vehicles. These three goals appear to have been achieved: Rumble strips were found to have a significant influence on traffic speed and STOP sign observance, and there also was a decreasing trend in the number of accidents.

13. POWERS, L. D., and MICHAEL, H. L., "Effects on Speed and Accidents of Improved Delineation at Three Hazardous Locations." *HRB Bull. 300* (1961) pp. 10-24.

    This paper reports the results of a study at three distinctive locations of the combined effect of various forms of delineation on driver speed patterns and on accidents. The locations concerned were a narrow bridge, a hazardous intersection, and an adequate intersection (all in rural areas). The various forms of delineation under consideration were roadside reflectors, pavement edge lines, signing, and, in one case, channelizing islands. Only free-moving passenger cars traveling on dry pavement under optimum day or night visibility conditions were considered in the speed study. The results were variable, but indicated a slight increase in speed and a slight reduction in accidents after the delineation. (Author)

14. ROWAN, N. J., "Approach-End Treatment of Channelization—Signing and Delineation." *Hwy. Res. Record No. 31* (1963) pp. 57-78.

The general objectives of the research project were to evaluate the effects of design, signing, delineation, and illumination of channelization on the factors of safety, efficiency of operation, and capacity. The specific phases of research covered in this report dealt with the signing and delineation of channelization, and with the effect of channelization and approach-end treatment on certain characteristics of driver behavior. (Author)

15. TAYLOR, E. W., "California Tests Raised Markers as Lane Lines." *Traffic Safety,* Vol. 66, No. 2 (Feb. 1966) pp. 20-21, 37-40.

California has installed more than 200 miles of both white and yellow "wedge-shaped" and "button-shaped" polyester resin markers since 1959. The report describes one of the earlier test sections. It has been found that the initial cost of raised markers is about equal to the first 10 years' expense of painted lines; however, the raised markers have an expected durability of at least 20 years on concrete pavement. The principal benefit measured was from incidental effects. The wedges alerted drowsy drivers and induced a safer distribution of traffic between the three lanes in one direction.

16. TAYLOR, W. C., *Colored Pavement Materials.* Bureau of Traffic Rep. No. 1-14862, Ohio Dept. of Highways.

The report describes a project that was designed to evaluate the use of colored pavement as a control and guidance device through intersections with left-turn slots. The area cross-hatched with white paint in the standard treatment was covered with yellow asphalt and the left-turn lane was covered with green asphalt. A before-and-after study was used to evaluate any changes in (1) approach speeds, (2) traffic flow patterns, and (3) lane position. Results indicated that the application of color did not cause the driver to decrease his speed when traversing the intersection. Vehicles exhibited a more uniform pattern of lane changing with colored asphalt during the day; however, colored asphalt had little effect on traffic flow patterns at night.

17. TAYLOR, W. C., and FOODY, T. J., "Ohio's Curve Delineation Program—An Analysis." *Traffic Eng.,* Vol. 36, No. 9 (June 1966) pp. 41-45.

A program to delineate all curves with a degree of curvature of 5° or greater on the state's first priority road system is analyzed. It is concluded that although the program is effective as a means of reducing traffic accidents, the degree of curvature alone is not a sufficient parameter for establishing delineation warrants. A better measure of delineation effectiveness is that of the central angle. (RRL)

18. TAYLOR, W. C., and HUBBELL, J. S., *The Evaluation of Pavement Marking to Designate Direction of Travel and Degree of Safety.* Bureau of Traffic Rep. No. 1-14163, Ohio Dept. of Highways (Nov. 1967) 35 pp.

The report describes a five-phase study conducted to determine some facts about the effectiveness of various pavement markings in terms of driver perception, understanding, and performance. Phase 1 consisted of a slide presentation depicting various pavement markings and marking systems. Phase 2 was an analysis of various markings on the material position of vehicles on curves. Phase 3 evaluated the merit of various markings as a deterrent to passing. Phase 4 was conducted to determine the driver's interpretation of pavement markings on a two-lane to four-lane transition. The final phase was conducted to determine perception and interpretation under a "no-stress" condition through interviews. The results indicated that neither yellow nor solid line alone conveyed a message of barrier. The lateral placement study indicated that drivers interpreted various line types differently when negotiating a curve. Other results are also discussed.

19. THOMAS, I. L., JR., "Pavement Edge Lines on Twenty-Four Foot Surfaces in Louisiana." *HRB Bull. 178* (1958) pp. 12-20.

The study was to determine the effect of edge lines on driver behavior. Different patterns of edge lines (none; 5-ft stripe, 40-ft centers; 10-ft stripe, 40-ft centers; and 2-ft stripe, 12-ft centers) at different distances from the pavement edge were tested. It was found that (1) vehicle placement during daytime is not appreciably affected by edge striping; (2) vehicle placement is unaffected by position of the edge stripe; (3) broken edge stripes have little or no effect on vehicle placement. Edge stripes tend to move the vehicle toward the center line. The psychological effect as determined by driver interviews was very favorable: during the day 88 percent of the drivers noticed them; at night 93 percent of the drivers saw them. Almost all the drivers who noticed the edge line understood its purpose. As speed increased, vehicles moved closer to the center line.

20. THOMAS, I. L., JR., and TAYLOR, W. T., JR., "Effect of Edge Striping on Traffic Operations." *HRB Bull. 244* (1960) pp. 11-15.

The study was to determine the effects of edge-lining on vehicle placement. The four test sections were 24-ft tangents, 20-ft tangents, 20-ft roadways on a 4° curve, and a four-lane divided highway. All the sections had contrasting shoulders. Results of the study indicate that edge lines have no effect on vehicle placement during the day, but at night tend to move the vehicle closer to the center line. However, the results are not statistically tested in the report.

21. TUTT, P. R., and NIXON, J. F., "Driver Communications Through Roadway Delineation." Texas Highway Dept. Rep. No. SS 12.1. Presented at Second Western Summer Meeting of HRB (Aug. 1969). Abridgment: "Roadside Design Guidelines." *HRB Spec. Rep. 107* (1970) pp. 119-132.

    The paper investigates the current practices in roadway delineation, with particular emphasis on delineation of freeway exit ramps. The merits and problems associated with current practices were investigated, particularly in the area of all-weather delineators and degree of association with the intended vehicular path through relatively complicated roadway geometrics. Reflectorized pavement markers having an internal reflective surface were found to be effective under wet-night conditions and also maintained an association with the intended path of the vehicle.

22. VAN VALKENBURG, G. W., and MICHAEL, H. L., "Criteria For No-Passing Zones." *Hwy. Res. Record No. 366* (1971) pp. 1 15.

    In establishing and marking no-passing zones on two-lane highways most states follow the short-zone concept that prohibits motorists from driving on the left side of a yellow line. An alternative is the long-zone concept that allows the yellow line to be crossed for the purpose of completing a passing maneuver and prohibits the beginning of a passing maneuver in a marked no-passing zone. The purpose of this study was to determine which no-passing zone concept should be adopted to assure maximum safety and comfort for the motoring public, and to determine appropriate criteria and legislation to implement the recommended concept. The results of the research indicate that the long-zone concept, which legally allows the completion of a passing maneuver within a no-passing zone, should be adopted. Criteria for marking no-passing zones and a model law required to implement the concept were developed.

23. WILLISTON, R. M., "Effects of Pavement Edge Markings on Operator Behavior." *HRB Bull. 266* (1960) pp. 8-27.

    This paper reports on Connecticut's study to determine what influence a paint stripe along the outer edge of the Merritt Parkway would have on operator behavior. Vehicle lane placement and speed measurements were made as an indication of operator behavior. It was concluded that on two-lane and four-lane divided highways the presence of a painted line along the outer edge of pavement affected the lateral position of vehicles and that edge markings appear to have some influence on operating speeds.

24. BABKOV, V. F., "What Constitutes a Safe Road." *Traffic Eng. and Control*, Vol. 11 (Oct. 1970) pp. 321-326.

25. BLENSLY, R. C., and HEAD, J. A., "Shoulders and Accident Experience on Two-Lane Rural Highways: A Summary." *HRB Bull. 266* (1960) pp. 28-33.

26. DARRELL, J. E. P., and DUNNETTE, M. D., "Driver Performance Related to Interchange Marking and Nighttime Visibility Conditions." *HRB Bull. 255* (1960) pp. 128-137.

27. FINCH, D. M., "Surface-Mounted Lights on Roadways for Guidance." *HRB Bull. 226* (1959) pp. 16-26.

28. HAMMER, C. G., and TAMBURRI, T. N., *Evaluation of Minor Improvements, Left Turn Channelization.* California Div. of Highways, Traffic Dept. (May 1968).

29. HUTCHINSON, J. W., and KENNEDY, T. W., "Safety Considerations in Median Design." *Hwy. Res. Record No. 162* (1967) pp. 1-29.

30. HUTCHINSON, J. W., and LACIS, J. H., "An Experiment with Evergreen Trees in Expressway Medians to Improve Roadway Delineation." *Hwy. Res. Record No. 105* (1966) pp. 85-98.

31. KASSEL, J. T., TAMBURRI, T. N., LUNDY, R. A., and ADACHI, H., *The Effect of Ramp Type and Geometry on Accidents.* California Highway Transportation Agency (May 1965).

32. KIHLBERG, J. K., and THARP, K. J., "Accident Rates as Related to Design Elements of Rural Highways." *NCHRP Report 47* (1968).

33. RICHARDS, H. A., ROWAN, N. J., and KANAK, E. W., "The Diagnostic Team Approach to Rail-Highway Grade Crossing Safety Evaluation." *Hwy. Res. Record No. 272* (1969) pp. 1-11.

34. ROWAN, N. J., and WILLIAMS, T. G., *Channelization.* Res. Rep. No. 19-4, Texas Transportation Inst., Texas A&M Univ. (Mar. 1966) 59 pp.

35. SCHEPP, A. J., and LAMB, D. R., "Shoulder Delineation Markings and Lateral Placement of Vehicles." *Public Works,* Vol. 96, No. 4 (Apr. 1965) pp. 118-120.

36. TAMBURRI, T. N., ET AL., "Evaluation of Minor Improvements." *Hwy. Res. Record No. 257* (1968) pp. 34-79.

37. TAMBURRI, T. N., and THEOBALD, D. J., *Reduced Visibility (Fog) Study.* California Div. of Highways (Mar. 1967).

38. TAYLOR, W. C., *Public Response to Color Coding.* Report No. 1-14867. Ohio Dept. of Highways, 12 pp. (1967).

39. TERRY, D. S., and KASSON, A. L., "Effects of Paint Channelization on Accidents." *Traffic Eng.*, Vol. 39, No. 3 (Dec. 1968) pp. 22-26.

40. YU, J. C., "A Comparative Analysis of Median Delineator Effectiveness." Presented at Second Western Summer Meeting of HRB (Aug. 1969). Abridgement: "Driver Performance Related to Median Visibility." *HRB Spec. Rep. 107* (1970) p. 180.

DELINEATION MATERIALS

41. Arizona Highway Department, *Delineators vs. Edge Stripe: Cost and Effect.* (June 1963) 26 pp.

The study was designed to test the cost effectiveness of edge stripe and post delineators along six sections of Arizona highways over a three-year period. It had the following results: (1) *Speed:* Night speeds increased with roadway delineation. Increase of night speed was greater with shoulder stripe than with post delineators. (2) *Placement:* Distance from center line decreased during night. There was no significant difference between shoulder stripe and post delineators with respect to vehicle placement day or night. (3) *Accidents:* Neither post delineators nor shoulder stripe had any deterrent effect on accident occurrence under conditions of this study. (4) *Cost:* The annual cost of shoulder striping makes it too expensive to use except for short sections where special driver guidance is needed. The use of post-mounted delineator plates is considered to be the most practical method of roadway delineation because it provides a satisfactory definition of pavement edge at a reasonable maintenance cost. Cost included initial installation and maintenance.

42. BEATON, J. L., and ROONEY, H. A., "Raised Reflective Markers for Highway Lane Lines." *Hwy. Res. Record No. 105* (1966) pp. 1-7.

A history of California's experimentation with raised reflective markers is presented. Button-type, wedge-type one-way and two-way, beaded and non-beaded, and reflex reflector pavment markers were studied. Findings indicate that the fully reflectorized markers (beaded) are ineffective for daylight delineation in clear and rainy weather. The fully beaded button marker is more effective in rainy weather at night than is the wedge marker. Glass beads used in the reflective button or wedge markers should contain the high index of refraction variety (1.90 minimum).

43. California Division of Highways, *Report on a Study of Highway Dividing (Lane) Markers.* House Resolution No. 462, State of California (Dec. 1962) 20 pp.

Various types of raised markers were studied to determine if raised reflective markers in the pavement could give adequate night visibility and good service life. British "Catseyes" (two lenses in a housing) were found to deteriorate quickly. Round buttons and wedge-shaped markers were found to be better and to offer better visibility. Various spacings were also tried.

44. CHAIKEN, B., "Comparison of the Performance and Economy of Hot-Extruded Thermoplastic Highway Striping Materials and Conventional Paint Striping." *Public Roads,* Vol. 35, No. 6 (Feb. 1969) pp. 135-156.

In the survey reported here, the comparative durability, performance, and economy of hot-extruded thermoplastic traffic-marking materials and conventional paint striping were evaluated. All state highway departments, major toll road agencies, and several larger cities and county road authorities were included in the survey, in which it was shown that the relative durability and long-term economy of hot-melt thermoplastic striping materials were greatly affected by type of pavement, snowplow activity, and traffic density. . . . Hot-extruded thermoplastic was found to be more economical than traffic paint under conditions of high traffic density and limited snowplow activity: otherwise, standard traffic paint was the more economical of the two methods of striping. Bituminous pavements showed the thermoplastics to better advantage than did portland cement concrete surfaces. (Author)

45. CHAIKEN, B., "Traffic Marking Materials—Summary of Research and Development." *Public Roads,* Vol. 35, No. 11 (Dec. 1969) pp. 251-256.

A summary of recent significant research and development in the field of traffic-marking materials is presented. The purpose of this review is to summarize the current state of the art since the last comprehensive bibliography, published in 1952 by the Highway Research Board. The subject matter is divided into the following topics: conventional solvent-based traffic paints, rapid-dry markings, semi-permanent markings, marking for improved night-wet visibility, and temporary lane markings.

46. "Colored Pavement has some Big Unsolved Problems." *Engineering News Record,* Vol. 179, No. 24 (Dec. 1967) pp. 41-43.

Colored standards as well as specifications are needed before colored concrete pavement can be universally accepted. The cost of colored pavement of synthetic resin is much greater than that of colored portland cement concrete. Synthetic resins require mixing of a pigment and binder. Cleanliness and temperature control are key factors in laying the hot-mixed colored pavement. Problems of fading are discussed, and colored aggregate is recommended as a solution. In addition to fading, colored pavement is obliterated by snow, and looks black or white when wet and at night. However, for effective traffic control, colored pavement is still recommended.

47. DALE, J. M., "Development of Formed-In-Place Wet Reflective Pavement Markers." *NCHRP Report 85* (1970).

The report describes the development of a new, low-cost technique for marking pavements that provides markings which are visible during periods of darkness and precipitation. The system consists of formed-in-place markers approximately 4 in. in diameter by 0.25 in. in height which are applied by a self-propelled machine. Nineteen 0.25-in.-diameter coated glass beads are dropped into an epoxy resin and submerged to just over their horizontal axis. Field testing showed that the performance of the markers was good in snow-free areas. In snowfall areas, damage from snowplow blades, studded snow tires, and chains was severe.

48. DALE, J. M., "Development of Improved Pavement Marking Materials—Laboratory Phase." *NCHRP Report 45* (1967).

This laboratory and field investigation presents an evaluation of pavement marking materials currently in use and a discussion of their shortcomings. A systematic approach for the design of a pavement marking system has been developed wherein one qualifies the surface to be marked, determines the water film thickness to be encountered, and then selects one of the several marking systems that will perform under the imposed conditions. Research points out that where pavement markings fail by mechanisms other than loss of their upper surface, a glass bead system having a uniform size gradation matched to the binder thickness should be used.

49. DAVID, J. H., and LETT, L., *A Study of the Effect of Using Colored Guide Posts on Interstate Highways to Reduce Accidental Damage.* HPR Report No. 33, Bur. of Research and Development, Alabama Highway Dept. (Aug. 1968).

Because of a high rate of damage to metal posts supporting delineators, Alabama painted the posts orange to contrast with the background. The study indicates that a modest savings could be realized by painting the posts.

50. FINCH, D. M., "Roadway Delineation with Curb Marker Lights." *HRB Bull. 336* (1962) pp. 105-109.

A system of small surface-mounted lights was designed to delineate a roadway at night. This paper reports one actual installation by the City of Oakland, Calif., on a section of winding road frequently enshrouded in fog. The illustrated paper shows these lighting devices (similar to raised markers), where they are installed, a picture taken at night, and actual cost and spacing. It discusses the suggested spacing of the devices in relation to curve radius.

51. GULLATT, S. P., JR., and CALHOUN, J. D., *Highway Lane Marking with Reflective Materials.* Project No. 736-00-86, Div. of Engineering Research, Louisiana Polytechnic Inst. (June 1967).

This report presents the details of an investigation related to the development of a detailed experimental program to be conducted as a Phase II effort which will determine the technical and economic feasibility of a highway lane marking system of raised pavement markers. This report covers the investigation of the highway visual environment and a determination of the information a driver needs from this environment. Cost and effectiveness measurement criteria have been established for comparing lane marking systems of raised pavement markers with marking systems using painted traffic striping. (Author)

52. KERMIT, M. L., and HEIN, T. C., "Effect of Rumble Strips on Traffic Control and Driver Behavior." *Proc. HRB,* Vol. 41 (1962) pp. 469-482.

This paper discusses the effects of rumble strips on driver behavior at four test locations in Contra Costa County, Calif. The results indicated the following: (1) accidents rates were greatly reduced, (2) STOP sign violations were significantly reduced, and (3) vehicle speeds and deceleration rates before a sharp curve were reduced. Explanations for reductions in accident rates and changes in driver behavior are based on the added visual, audible, and tactile stimuli produced by the rumble strips. These strong signals help alert the driver to changing road conditions. Economic justification for the strips is analyzed in terms of accident cost reduction.

53. ROONEY, H. A., and SHELLY, T. L., *Development and Evaluation of Raised Traffic Lane Markers, 1953 to 1968.* Res. Rep. No. 635152, California Div. of Highways (June 1968).

The State of California has evaluated and adopted a system for delineating traffic lanes using raised pavement markers for most areas of the state. Four white non-reflective markers are placed on 3-ft centers followed by a 15-ft gap. A reflective marker is placed in the center of every other gap on tangents. Raised yellow markers are used at the left edge of the lane near the median of divided highways. This system is much more durable than traffic paint, gives excellent nighttime visibility in good weather, and provides good nighttime visibility in all but heavy fog. (Author)

54. ROONEY, H. A., and SHELLY, T. L., *Interim Report on Plastic Tapes Compared to Extruded Thermoplastic Traffic Paint Used for Traffic Lane Delineation.* Materials & Research No. 645135, California Div. of Highways (Mar. 1967).

The report describes field results observed on two traffic lane markers—a beaded white plastic tape and a thermoplastic white material. Plastic tape was found to be less durable on crosswalks than the thermoplastic stripe. Nighttime visibility of the beaded thermoplastic is superior to that of the beaded plastic tape. The plastic tape costs about twice as much as the thermoplastic stripe.

55. TARAGIN, A., and RUDY, B. M., "Traffic Operations as Related to Highway Illumination and Delineation." *HRB Bull. 255* (1960) pp. 1-29.

Driver behavior data were recorded under nine different conditions of highway illumination and delineation at one on-ramp and one off-ramp on a mercury-illuminated section of the Connecticut Turnpike. The results showed no significant differences with respect to average vehicle speeds, lateral placements, and clearances between vehicles. In general, it appears that some beneficial results of illumination in the deceleration area are derived when it is used at the full level and that even greater service is provided when illumination is combined with roadside delineation.

56. U.S. Coast Guard, *Photometric Tests of Retro-Reflective Materials.* Field Testing and Development Unit Rep. No. 359 (Dec. 1963) 25 pp.

Photometric properties of four different types of retro-reflective delineators were measured. Specific intensities of each reflector in candles per footcandle were determined as a function of angle of incidence for angles of divergence of 0.1° and 0.25°. Clear red, green, and yellow retro-reflectors were tested. The effect of simulated rainfall was determined, as was the effect of spectral variation of the light source on the reflectance of the colored reflectors.

57. BINGHAM, E. C., "Controlled Reflection. A Plan for Greater Safety in Night Driving." *Proc. HRB*, Vol. 24 (1944) pp. 147-157.
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59. CHRISTIE, A. W., REID, J. A., RUTLER, K. S., and WALKER, A. E., "Edge Markings for Roads with Flush Shoulders." *Traffic Eng. and Control*, Vol. 4, No. 9 (Jan. 1963) pp. 500-504, 509.
60. CODY, L. W., *Semi-Permanent Traffic Striping*. Res. Proj. HR-178, Washington Dept. of Highways (May 1, 1967).
61. "Color Coding of Entry and Exit Ramps." *American Engineer*, Vol. 32, No. 4, pp. 42-44 (Apr. 1962).
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63. Colorado Department of Highways, *Reflective Traffic Bead Study*. 3d Interim Report (July 1968).
64. Colorado Department of Highways, *Colorado's Reflective Bead Study*. (Nov. 1968).
65. "Colorful Intersection." *Better Roads*, Vol. 33, No. 10 (Oct. 1963) p. 12.
66. "Coloring Highways as a Guide to Motorists is Being Tested Here and Abroad." *Rock Products*, Vol. 62, No. 1 (Jan. 1959) p. 14.
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68. COOK, K. G., *Reflector Analysis*. Century Research Corp., USDOT Contract FH-11-6950 (Aug. 1969).
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70. "Drivers Get a Lift from Raised Lane Markers." *American City*, Vol. 81, No. 5 (May 1966) p. 147.
71. FARRIMOND, K. D., *Use of a Rumble Stripe to Reduce Maintenance and Increase Driving Safety: Interim Report*. Res. Rep. 500-901, Utah State Dept. of Highways (Dec. 1968) 26 pp.
72. FITZPATRICK, J. T., "Unified Reflective Sign, Pavement and Delineation Treatments for Night Traffic Guidance." *HRB Bull. 255* (1960) pp. 138-145.
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75. HAVENS, J., and SCOTT, J. W., *Experimental Use of Thermoplastic Pavement-Striping Materials*. Rep. No. 3, Kentucky Dept. of Highways (May 15, 1964).
76. HISS, J. G. F., JR., and MCCARTY, W. M., *Glass Beads for Traffic Paints*. N.Y. DOT Res. Rep. 66-4 (Dec. 1966).
77. HISS, J. G. F., JR., ET AL., *Pavement Marking Paints: Interim Report*. N.Y. DOT Res. Rep. 67-4 (Mar. 1969).
78. "How to Keep Safety Delineators on the Job." *Rural and Urban Roads*, Vol. 6, No. 9 (Sept. 1968) pp. 32-33.
79. HOYT, D. W., "In Further Support of Rumble Strips." *Traffic Eng.*, Vol. 39, No. 2 (Nov. 1968) pp. 38-41.
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83. Maintenance Department, Iowa State Highway Commission, *Traffic Line Markings on Primary Roads*. (May 1966) 70 pp.
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99. "White Bituminous Mix Gets Expressway Test." *Roads & Streets,* Vol. 105, No. 2 (Feb. 1962) pp. 103-106.
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101. "Yellow Lane for Left Turns." *American City,* Vol. 78, No. 7 (July 1963) p. 9.
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PRACTICES IN OTHER COUNTRIES

103. JAMES, J. G., and REID, J. A., "Notes on the Costs, Lives and Effectiveness of Various Road Markings." Road Research Laboratory, Ministry of Transport, RRL Report LR 285, Crowthorne (1969).

    From February 1965 to February 1968 a "Panel on Road Markings" met regularly to examine, discuss, and advise on the layout of road markings and the materials to be used. This report brings together some of the data obtained over those three years and summarizes the main findings of the Panel. The latter relate primarily to edge markings.

104. LAKE, J. R., and TYLER, J. W., *The RRL Reflecting Kerb.* Road Research Laboratory, Ministry of Transport, RRL Report LR 89 (1967).

    This report describes a new type of reflecting concrete curb designed by the Road Research Laboratory (England). Light from vehicle's headlights is reflected back to the driver by facets formed by the edges of raised rectangular pads on the sloping face of a 45° curb. Observations made at night in both dry and wet conditions show that the curb provides a good definition of the edge of the carriageway, and the performance is affected little by roadside dirt.

105. REID, J. A., and TYLER, J. A., "Reflective Devices as Aids to Night Driving." *Highways & Traffic Engineering,* Vol. 37, No. 1715 (July 1969) pp. 34-36, 38, 41-42.

    This article presents a good, general description of reflective devices available in England as aids to night driving. The following types of reflective devices are discussed: (1) reflective road signs, (2) reflective curbs, (3) reflective road and edge markings, and (4) reflective road studs. A subjective and objective assessment is made for the various devices.

106. *United Nations Conference on Road Traffic—Final Act and Related Documents.* United Nations, New York (1969) 169 pp.

    This U.N. document contains the final act on the convention on road traffic and on road signs and signals for international use.

107. "Colored Concrete Pavements Experiment in Germany." *World Road News,* Vol. 1, No. 2 (Feb. 1966) p. 21.
108. DALE, J. M., "Pavement Marking—Danish Style." *Better Roads,* Vol. 40, No. 2 (Feb. 1970) pp. 28-30.
109. KIRCHNER, S., "Traffic Signs and Markings in the German Democratic Republic." *Traffic Eng. and Control,* Vol. 11 (Oct. 1970) pp. 316-317.
110. SILYANOV, V. V., "Report from the Soviet Union Carriageway Marking Tests in the U.S.S.R." *Traffic Eng. and Control,* Vol. 9 (Dec. 1968) pp. 409-412.

HUMAN FACTORS—GENERAL

111. ALGEA, C. W., "A Development of a Conceptual Framework of the Driving Task." *Human Factors,* Vol. 6, No. 4 (Aug. 1964) pp. 375-382.

    After development of a conceptual framework based on driving behavior in actual traffic conditions, the assumptions and implications are contrasted with those in nondriver-oriented traffic flow theories. It appears that the elimination of the driver in modeling work to simplify the mathematics is justified.

112. ALLEN, M. J., "Vision and Driving." *Traffic Safety,* Vol. 69, No. 9 (Sept. 1969) p. 8.

    This article looks at various relationships between vision and driving (i.e., dynamic visual acuity, static visual acuity, peripheral visual fields, stereopsis, color vision, effects of alcohol, smoking, glare resistance, night acuity, drugs, fatigue, and age). This review concludes with some "helpful hints" for public education campaigns.

113. BJORKMAN, M., "An Exploratory Study of Predictive Judgments in a Traffic Situation." *Scand. J. Psychology,* Vol. 4 (1963) pp. 65-76.

    The study is an investigation of how veridically an observer seated in a car can predict where he will meet an oncoming car. Even after training veridicality is still low, indicating non-support for the hypothesis that "reinforcement by observation" improves predictions. Driver will make biased predictions of meeting points, and this may be fatal, for example, in overtaking situations.

114. BLACKWELL, H. R., SCHWAB, R. U., and PRITCHARD, B. S., "Visibility and Illumination Variables in Roadway Visual Tasks." *Illuminating Engineering,* Vol. 59 (May 1964) pp. 277-308.

    Study was carried out to determine the amount of light needed to perform each of several visual tasks. Recommendation: because of the great variance in required brightness levels, the brightness provided for any given street lighting system must be a function of the visual task to be performed.

115. CUMMING, R. W., "The Analysis of Skills in Driving." *Australian Road Research* (Mar. 1964) pp. 4-15.

Skills involved in driving a motor vehicle are analyzed in terms of known characteristics of human performance, the most significant of which is the rate at which it is possible to make successive decisions. Recent human performance findings are used to build a conceptual model of the human operator as a decision maker. The driver's task—seen as a perception, decision-making, and control model, and defined by the limits rather than the average of human performance characteristics—is then discussed as a tool in the design of roadway systems.

116. FELDHAUS, J. L., JR., "Dynamic Visual Acuity—Effect on Night Driving and Highway Accidents." *HRB Bull. 298* (1961) pp. 1-2.

This paper examines dynamic visual acuity as related to angular velocity (viewing a stationary object while traveling at a given speed). This is an evaluation of the work of Elek Ludvigh of the Kresge Eye Institute and James Miller of the U.S. Naval School of Aviation Medicine. Based on the fact that in all cases if the angular velocity was zero, the visual acuity was 20/20 Snellen, calculations show that when one is driving at 60 mph and looking at an object 20 ft from the car, the driver's visual acuity will be between 20/121 and 20/317; at 30 mph, the visual acuity will be between 20/70 and 20/150. Therefore, there is a definite advantage to reducing driving speed. Also, further investigation by Ludvigh and Miller indicated that dynamic visual acuity is greatly increased by increasing the illumination falling on the object of regard.

117. JONES, M. R., "Color Coding." *Human Factors,* Vol. 4, No. 6 (Dec. 1962) pp. 355-365.

Research published in the last decade on color as a coding device is discussed. Findings indicate that a reliable unidimensional hue code should not contain more than about eight optionally spaced stimuli. In addition, color codes do not appear to be suited to situations that demand rapid and precise identification; however, they are valuable in decreasing search time with locate-type tasks.

118. MICHAELS, R. M., "Human Factors in Highway Safety." *Traffic Quart.,* Vol. 16, pp. 586-599 (Oct. 1961).

As a basis for the discussion of human factors, this paper begins by discussing accident causality, treating both the specific and the multifactor approach, and ultimately concludes that neither is alone an adequate representation because of the large degree of random error involved in accident occurrence. In short, accidents are seen as events not specifically caused or predictable. This implies that the problem must be redefined. The redefinition is provided in terms of system and error. Definitions of variable and constant errors are provided. The same system is defined as one in which the variable errors have been minimized. Then, seen in these terms, the objective of highway safety is to increase the reliability of the driving system. Human factors is seen to fit in to this redefinition, as the performance limits imposed by man's capacities. The problem is examined in the context of two questions: (1) What kind of operations does driving require of man? and (2) How well do human capabilities satisfy these requirements? An information-processing model is presented, a role of learning is examined, and man's capabilities as a control component are assessed. These conceptualizations are given operational meaning in terms of removing or reducing the points of uncertainty from the driving situation, thus making it more compatible with man's limited capacities.

119. MULLEN, E. F., "The Part Visibility Could Play in Road Design." *Australian Road Research* (Sept. 1966) pp. 15-42.

This article discusses limitations of man in handling a motor vehicle at high speed. Emphasis is placed on "seeing" (defined as perception of retinal image). Physiological aspects (such as dynamic acuity, dark-light adaptation, effects of alcohol, fatigue, and intoxicants) are discussed in detail. The interactions of these perception elements and such physical limitations as ambient illumination, object height and eye height, peripheral vision (both side and overhead) as related to vehicle design, and headlight efficiency are discussed in relation to highway design.

120. PLATT, F. N., "Operations Analysis of Traffic Situation." *Traffic Safety and Res. Rev.,* Vol. 2, No. 4 (Dec. 1958).

This article lists and defines a number of traffic situations and human sensory modalities and discusses the interface between the two. Suggestions are made for further research.

121. SCHLESINGER, L. E., and SAFREN, M. A., "Perceptual Analysis of the Driving Task." *Hwy. Res. Record No. 84* (1963) pp. 54-61.

This paper attempts to develop a unified and comprehensive model of the driving task that has practical and psychological validity. The model specifies the critical tasks of driving, the critical skills to perform these tasks, and some objective measures of these skills. In the model, the major tasks for the driver are the perceptual organization, from moment to moment, of a field of safe travel (a region in which the car can move unimpeded), a minimum stopping zone (the smallest region through which the car must move to come to a full stop), and a comparison of these two fields. The driver's organization of these two fields, or the field-zone ratio, is a control stimulus guiding the control actions to the vehicle. That is, the driver varies the speed and direction of movement of the vehicle to maintain a safe field-zone ratio—one in which the field is greater than the zone. Objective measures of driving skill derived from the model include the "smoothness" of driving, measured by speed and direction changes over time; i.e., if the driver from moment to moment

correctly perceives his field of safe travel and minimum stopping zone and maintains his field of safe travel greater than the minimum stopping zone, he has little occasion for sudden and jerky movements because of contingencies that could have been foreseen. Experiments are designed to test the predictions derived from the model and to further develop the model.

122. ADAMS, J. A., "Some Mechanisms of Motor Responding: An Examination of Attention." In E. A. Bilodeau (Ed.), *Acquisition of Skill,* Academic Press (1966).

123. BLACKWELL, R. H., SCHWAB, R. N., and PRITCHARD, B. S., "Illumination Variables in Visual Tasks of Drivers." *Public Roads,* Vol. 33, No. 11 (Dec. 1965) pp. 237-248.

124. BRAUNSTEIN, M. L., and LAUGHERY, K. R., "Detection of Vehicle Velocity Changes During Expressway Driving." *Human Factors,* Vol. 6, No. 4 (Aug. 1964) pp. 327-331.

125. CONNOLLY, P. L., "Adapting Vehicle and Highway to Suit Man's Visual Limitations Can Bring Big Safety Dividends." *SAE Journal,* Vol. 74, No. 8 (Aug. 1966) p. 44.

126. DUNNETTE, M. D., "Driver Opinions and Reported Performance Under Various Interchange Marking and Nighttime Visibility Conditions." *J. Applied Psychology,* Vol. 45, No. 3 (1961) pp. 170-174.

127. ELY, J. H., BOWEN, H. M., and ORLANSKY, J., *Man-Machine Dynamics.* USAF WADC, Tech. Rept. No. 57-582 (Nov. 1957).

128. GELDARD, F. A., *The Human Senses.* Wiley (1953).

129. GIBBS, C. B., "Methodology of Gain Studies in Man-Machine Systems." *Psychological Bull.,* Vol. 60 (1963) pp. 147-151.

130. GIBSON, JAMES J., "A Theoretical Field-Analysis of Automobile Driving." *Am. J. Psychology,* Vol. 51, No. 3 (July 1938) pp. 453-471.

131. GOLDSTEIN, L. G., "Human Variables in Traffic Accidents: A Digest of Research." *Traffic Safety and Res. Rev.,* Vol. 8, No. 1 (Mar. 1964).

132. GOLDSTEIN, L. G., *Research on Human Variables in Safe Motor Vehicle Operation: A Correlational Summary of Predictor Variables and Criterion Measures.* Driver Behavior Research Project, George Washington Univ. (June 1961).

133. HELSON, H., "Design of Equipment and Optimal Human Operation." *Am. J. Psychology,* Vol. 62 (1949) pp. 473-479.

134. HEMSTRA, N. W., and JONES, H. V., "Ability of Drivers to Make Critical Passing Judgments." *J. Engineering Psychology,* Vol. 3 (1964) pp. 117-122.

135. HOFFMANN, E. R., "Note on Detection of Vehicle Velocity Changes." *Human Factors,* Vol. 8, No. 2 (Apr. 1966) pp. 139-141.

136. HOSTETTER, R. S., and SEGUIN, E. L., "The Effects of Sight Distance and Controlled Impedance on Passing Behavior." *Hwy. Res. Record No. 292* (1969) pp. 64-78.

137. HULBERT, S. F., and BURG, A., "Application of Human Factors Research in Design of Warning Devices for Highway-Rail Grade Crossings." In Schoppert, D. W., and Hoyt, D. W., "Factors Influencing Safety at Highway-Rail Grade Crossings." *NCHRP Report 50* (1968) pp. 82-105.

138. KLEMMER, E. T., *Discrete Tracking in One and Two Dimensions.* USAF CRC, Res. Rept. No. 56-2 (Apr. 1956).

139. KOCH, S. (Ed.), *Psychology: A Study of a Science.* Vol. 1, McGraw-Hill (1959).

140. MACE, D. J., HOSTETTER, R. S., SEGUIN, E. L., *Information Requirements for Exiting at Interchanges.* Contract No. CPR-11-2808, Bur. Pub. Roads (Sept. 1967).

141. GORDON, D. A., and MAST, T. M., "Drivers' Decisions in Overtaking and Passing." *Public Roads,* Vol. 35, No. 4 (Oct. 1968) pp. 97-101.

142. "More Light for Night Driving." *Traffic Safety,* Vol. 60 (May 1960) pp. 20-22.

143. PLATT, F. N., "Operations Analysis of Traffic Safety—Part II." *Traffic Safety and Res. Rev.,* Vol. 3, No. 2 (June 1959).

144. RICHARDS, O. W., *Visual Needs and Possibilities for Night Automobile Driving.* American Optical Corp. Report (Aug. 1967).

145. ROCKWELL, T. H., ERNEST, R., and RULON, M. J., "Visual Requirements in Night Driving." *NCHRP Report 99* (1967) Chapters 3, 4, 5, 6.

146. RUMAR, K., *Visible Distances in Night Driving.* Dept. of Psychology, Univ. of Uppsala, Sweden, 44th Report (July 1967).

147. SALVATORE, S., "The Estimation of Vehicular Velocity as a Function of Visual Stimulation." *Human Factors,* Vol. 10, No. 1 (Feb. 1968) pp. 27-32.

148. SALVATORE, S., "Vehicle Speed Estimation from Visual Stimuli." *Public Roads,* Vol. 34, No. 6 (Feb. 1967) pp. 128-131.

149. SCHMIDT, I., *Visual Considerations of Man, the Vehicle, and the Highway.* Indiana Univ., SAE-SP-279, pt. 1 (1966).

150. SCHWAB, R. N., "Night Visibility for Opposing Drivers with High and Low Headlight Beams." *Illuminating Engineering,* Vol. 60 (May 1965) pp. 364-372.

151. SIELSKI, M. C., "Night Visibility and Traffic Improvement." *Traffic Eng.,* Vol. 36, No. 8 (May 1966) pp. 28-31.

152. STEVENS, S. S. (Ed.), *Handbook of Experimental Psychology.* Wiley (1951).

153. WELFORD, A. T., "The Measurement of Sensory-Motor Performance: Survey and Reappraisal of Twelve Years Progress." *Ergonomics,* Vol. 3 (1960) pp. 189-231.

VISUAL PERCEPTION

154. BURG, A., and HULBERT, S., "Dynamic Visual Acuity as Related to Age, Sex, and Static Acuity." *J. Applied Psychology,* Vol. 45, No. 2 (1961) pp. 111-116.

The study contains: (1) independent verification of Ludvigh and Miller's results on the relationship between dynamic visual acuity (DVA) and static acuity; (2) the relationship between DVA and other visual measures such as critical flicker frequency (CFF) and lateral phoria (stated in terms of ACA ratio), as well as nonvisual factors (i.e., age and sex), (3) performance with free-head movement and with fixed-head position. Results indicated: (1) No correlation between CFF and ACA ratio or between either CFF or ACA ratio and either static or dynamic acuity. (2) Low but significant correlation found between DVA and Ortho-Rater static acuity, the correlation decreasing with increasing target velocity, and a lower and less consistent correlation for fixed-head DVA than for free-head DVA. (3) With the exception of fixed-head DVA, tests-retest reliability was significant. (4) Males showed better performance. The progressing decrease in acuity for a moving target as the target velocity increases indicates that factors other than static acuity play an important part in determining an individual's ability to discriminate a moving object.

155. BURG, A., "Visual Acuity as Measured by Dynamic and Static Tests: A Comparative Evaluation." *J. Applied Psychology,* Vol. 50, No. 6 (1966) pp. 460-466.

This paper compares static and dynamic acuity performance; it uses a large, heterogeneous sample not only to assess the validity of the various research findings obtained heretofore but also to provide performance norms of value to other researchers working in this area. Results indicated: (1) the decrease in acuity with increased speed was expected in view of the accommodation-pursuit tracking task; (2) high correlations between static and dynamic tests were due to the large heterogeneous sample and non-acuity factors; (3) the decrease with age was due to physical or physiological functions.

156. EPSTEIN, W., PARK, J., and CASEY, A., "The Current Status of the Size-Distance Hypotheses." *Psychological Bull.,* Vol. 58, No. 6 (Nov. 1961) pp. 491-514.

This article constitutes a survey report on the status of the Size-Distance Invariance Hypothesis and its corollaries. The author summarizes at one point by noting that the size-distant relationship expressed in several formulations of the invariance hypothesis should not be assigned a unique or primary status in explanations of space perceptions. Although there is a great deal of experimental support for this hypothesis several other possible and actual relationships between size and distance also exist. An extreme variability in individual subjects is not explained by the invariance hypothesis.

157. COGEL, W. C., "The Absolute and Relative Size Cues to Distance." *Am. J. Psychology,* Vol. 82, No. 2 (June 1969) pp. 228-234.

The purpose of this study was to clarify a proposed differentiation between absolute and relative cues by examining the effect of temporal separation between presentations on the relation between retinal size and perceived distance. In the laboratory setting the experimenter compared the perceived distances obtained from first successive and simultaneous presentations of different retinal sizes of a familiar object. On the first presentation, on the average, the perceived distance of the object increased with a decrease in retinal size; this increase was considerably less than that shown between second presentations. This change was predicted by considering the data resulting from the first and simultaneous perceptions together. The author suggests that the method of using different groups and different orders of presentations would also be useful in differentiating between absolute and relative cues in cue systems other than that of familiar size.

158. MOUNT, G. E., CASE, H. W., SANDERSON, J. W., and BRENNER, R., "Distance Judgments of Colored Objects." *J. Gen. Psychology,* Vol. 55 (1956) pp. 207-214.

This study examines the effect of color differences on the perception of relative distance and the outdoor viewing situation. The results demonstrate dependence of judgments of distance on the difference in brightness of the two standards on the relative brightness differences of the comparison stimuli and on the differences between hue and gray comparisons; i.e., in each case, stimuli that contrasted most with the background were seen in front of stimuli that contrasted relatively less with the background.

159. RICHARDS, O. W., "Night Driving Seeing Problems." *Traffic Safety and Res. Rev.,* Vol. 3, No. 2 (1959) pp. 22-28.

This paper is a discussion of decrements in visual perception because of low visibility levels and nighttime driving. Discussed are colored lenses, night myopia, fatigue, and tinted windshields. The author suggests that proper training for nighttime seeing should help drivers compensate for low-visibility problems. Specific suggestions are offered as a basis for this training.

160. WEISSMAN, S., and FREEBURNE, C. M., "Relationship Between Static and Dynamic Visual Acuity." *J. Exp. Psychology,* Vol. 70, No. 2 (1965) pp. 141-146.

This study investigates the relationship between dynamic acuity (DVA) and static acuity (SVA) at a wide range of speeds. Seven Landolt rings were presented in each of four positions at angular velocities of 20, 60, 90, 120, 150, and 180°/sec, to subjects tested binocularly and with free-head movement. All seven internal consistency reliability coefficients were significant at the 0.01 level. At all but the two fastest speeds, relationships between DVA and SVA were significant (0.01 level). DVA thresholds at four lowest speeds showed linear relationships with SVA thresholds. The relationship between 150°/sec and 180°/sec is nonlinear. Acuity for a moving target deteriorated progressively as the target velocity increased. With a restricted range of

static acuity thresholds, DVA thresholds at a wide range of speed tend to deviate greatly from SVA scores. At a wide variety of static acuity thresholds, the DVA thresholds obtained at various speeds were more related to static acuity thresholds.

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168. ERICKSON, R. A., "Relation Between Visual Search Time and Peripheral Visual Acuity." *Human Factors*, Vol. 5, No. 2 (Apr. 1964) pp. 165-177.
169. *Field of Vision as Related to Age.* AAA Research Rep. No. 67 (Apr. 1958).
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190. WOLF, E., MCFARLAND, R. A., and ZIGLER, M., "Influence of Tinted Windshield Glass on Five Visual Functions." *HRB Bull. 255* (1960) pp. 30-46.

INFORMATION PROCESSING

191. ALLUISI, E. A., MULLER, P. F., JR., and FITTS, P. M., *Rate of Handling Information and the Rate of Information Presentation.* USAF WADC, Tech. Note No. 55-745 (Dec. 1955).

A study to determine whether the rate of handling information in a forced-paced serial task was a function of (1) the rate of stimulus presentation, (2) the uncertainty per stimulus, or (3) the joint effect of these expressed as the rate of information presentation per se. Using a strict information theory approach, they found that, for a given constant rate of *information* presentation, an increased rate of infor-

mation transmission was obtained by increasing the number of possible alternative stimuli and decreasing the rate of stimulus presentation. This indicates that the rate of handling information is a function of both uncertainty per stimulus and stimulus presentation rate. Significant decrements in the relative information transmission rate were obtained with increases in the rate of stimulus presentation, but increases in the number of possible alternative stimuli produced no significant changes. This indicates that the increase in *absolute* information handling ability that results from increasing stimulus uncertainty is apparently achieved without an appreciable loss in the relative accuracy of responses. An interaction of stimulus presentation rate with stimulus complexity was shown in the distribution of the responses omitted. The percentage of omitted responses was relatively unaffected by increases in stimulus uncertainty at the lower rates of stimulus presentation, but was markedly increased by increases in uncertainty at the higher rates of presentation. In general, the results of this study suggest that individuals can handle information with a large set of stimuli and responses more efficiently than with a small set of alternative stimuli and responses. The authors point out that this is in direct opposition to the accepted fact that a binary code is most efficient for electronic computers and communications, and may represent an interesting difference between human and hardware information-handling systems.

192. Bartlett, N. R., Bartz, A. E., and Wait, J. V., "Recognition Time for Symbols in Peripheral Vision." *HRB Bull. 330* (1962) pp. 87-91.

This study reports on the development of a transportable recording system that can be used in moving vehicles to (1) record driver eye movements, and (2) investigate human response times to signals in peripheral vision. It was found that response time increased as the angle from the center line of direct vision increased, and that response time increased as the number of possible signals increased. The author concludes by stating that response times are usually long in a complex visual situation and suggests that further research may yield a mathematical relationship between response time and number of stimuli.

193. Fitts, P. M., and Seeger, C. M., "Compatibility: Spatial Characteristics of Stimulus and Response Codes." *J. Exp. Psychology,* No. 46 (1953) pp. 199-210.

This study tested the hypothesis that information transfer in a perceptual-motor task is largely a function of the matching of sets of stimuli and sets of responses. The authors used nine stimulus-response (S-R) ensembles in an eight-choice situation, the S-R ensembles involving variations of the spatial patterns of stimuli and responses. The evaluative measures used were: reaction time, percentage of responses that were in error, and average information lost per stimulus. The results indicate that it is not permissible to conclude that any particular set of stimuli or set of responses will provide a high rate of information transfer; rather, it is the ensemble of S-R combinations that must be considered. A second study was conducted to test the permanence of three selected S-R compatibility effects. Subjects were trained for 32 days to make a particular set of responses to each of 3 sets of stimuli. Differences in reaction time, in movement time, and in frequency of errors in responding to the three sets of stimuli were found to persist over 32 days. The results are interpreted in terms of probability learning and the necessity for (hypothetical) information, transformation, or reencoding steps. The data suggest that it is difficult for subjects to learn to deal effectively with the information characteristics of a specific situation if these uncertainties are different from the more general set of probabilities that have been learned in similar life situations.

194. Fitts, P. M., Peterson, J. R., and Wolfe, G., "Cognitive Aspects of Information Processing: II, Adjustments to Stimulus Redundancy." *J. Exp. Psychology,* Vol. 65, No. 5 (1963) pp. 423-432.

Three experiments are reported in which relative stimulus frequencies were varied in nine choice tasks. The tasks involved naming numbers and pointing to lights. It was found that, as redundancy increased, average reaction times (RT's) to the frequent stimulus component decreased, whereas RT's to less frequent components increased, the differences being a linear function of redundancy. These effects were greater for the less compatible (vocal) task. The subjects used the frequent response more often and the infrequent response less often than appropriate in responding to redundant sequences. These results are in agreement with predictions from a stimulus sampling and sequential decision model in which it is assumed that RT's and errors are a function of prior probabilities and the payoff matrix for correct and wrong, slow, and fast responses, as well as a function of stimulus discriminability.

195. Hannes, M., Sutton, S., and Zubin, J., "Reaction Time: Stimulus Uncertainty With Response Certainty." *J. Gen. Psychology,* Vol. 78 (1968) pp. 165-181.

If no choice is required of the subject (i.e., he makes the identical response regardless of which stimulus is presented), will reaction time to a particular stimulus be altered as a function of the probability with which that stimulus follows another stimulus? Reaction time to one of two alternative stimuli (sound) is considered as a function of varying sequential dependency in a situation in which response information and transmitted information are zero. (1) Despite the fact that only stimulation information is varied, reaction time to sequential uncertain stimuli is longer than reaction time to sequential certain stimuli. (2) Reaction time is sensitive to the degree of stimulus uncertainty if the sequence involves a shift in sensory modality, but not if the sequence involves no shift in sensory modality.

(3) When one is averaging across two subjects, the relationship between reaction time and stimulus information is linear if the sequence is crossmodal. (4) Practice does not appear to alter these relationships.

196. HODGE, M. G., "The Influence of Irrelevant Formation Upon Complex Visual Discrimination." *J. Exp. Psychology*, Vol. 57 (1959) pp. 1-5.

The report attempts to determine whether increasing amounts of irrelevant information, which is relevant under other conditions, detrimentally influences the performance of a complex discrimination task. Also examined were: (1) whether the effect of the irrelevant information is increased as the discrimination of the relevant information is made more difficult, and (2) whether the effect of the irrelevant information is reduced by practice. Response latency differences among the irrelevancy conditions were significant. Both the discrimination and practice variables were significant, but only the practice vs irrelevancy interaction was significant. The error data support the results of the latency analysis.

197. KORNBLUM, S., "Sequential Determinants of Information Processing in Serial and Discrete Choice Reaction Time." *Psychological Rev.*, Vol. 76, No. 2 (Mar. 1969) pp. 113-131.

In most experiments supporting the linear relationship between choice reaction time (RT) and average stimulus information (H), the results are confounded with the probability of nonrepetition of the stimuli. This experiment was designed to unconfound these two variables, and thus led to a rejection of the information hypothesis. The RT for repetitions is found to be faster than for nonrepetitions, and both are decreasing linear functions of their respective conditional probabilities. Discussion focuses on the manner in which the slope and intercepts of these linear functions are affected by changes in number of alternatives, stimulus-response compatibility, and response-to-stimulus interval.

198. KRULEE, G. K., and SINCLAIR, E. J., "Some Behavioral Implications of Information Theory." Naval Res. Lab. Rep. No. 4119 (1953).

In this research, the authors obtained data that implied that the complexity of the process of elimination of irrelevant information seemed to depend on whether it was perceptually possible for a subject to minimize the information load of irrelevant messages by treating them as a single category of information. This result suggests that non-directional highway signs and other signs such as advertising signs *may* not have a detrimental effect on the over-all information processing task of the driver, inasmuch as it is likely that they can be treated as a single category and therefore disregarded immediately. This, of course, requires that directional signs be unique and that some narrow range of size constancy, color, etc., be maintained.

199. MILLER, G. A., "The Magical Number Seven, Plus or Minus Two, Some Limits on Our Capacity for Processing Information." *Psychological Rev.*, Vol. 63, No. 2 (Mar. 1956) pp. 81-97.

This is a paper originally given as an address reviewing, describing, and explaining some of the facets of information-processing theory, channel capacity, their interrelationship, and other psychological precepts.

200. MACKWORTH, N. H., and MACKWORTH, J. P., "Visual Search for Successive Decisions." *Brit. J. Psychology*, Vol. 49 (1958) pp. 210-221.

This study was an investigation of the role of display density or load on the average demanded speed of decision in a visual search task. Five groups of subjects were tested at four levels of display load and at five demanded speeds of decision. Results indicated: (1) Both speed and load are significantly important in ordered search task. (2) Load is linearly related to performance in terms of error. (3) Speed of decision is also linearly related to performance in terms of error. (4) Effects of load increase with the speed of work. (5) Effects of speed increase with load. (6) Effects of load and speed of work are not simply additive. One particular, relevant point is that sense speed, in terms of the number of decisions demanded, is a product of the number of sources and the speed at which each source is requiring decisions; then, whenever the number of sources is increased, the rate of decisions coming in from each source must be reduced considerably to hold constant the product of average speed and load.

201. NICKSON, R. S., "Response Times With a Memory Dependent Decision Task." *J. Exp. Psychology*, Vol. 72, No. 3 (1966) pp. 761-765.

Four experiments were conducted to determine the time required to make some simple memory-dependent decisions. Subject's task was to decide whether any of the items of a memorized checklist were contained in a visually displayed search list, and to register his decision as quickly as possible by pressing one of two response keys. Reaction time (RT) varied directly with both the number of items in the checklist and the number in the search list, and inversely with the number of items common to both lists. Practice reduced RT across conditions, and it also decreased, but did not eliminate, the effects of the independent variables. Decreases in RT with practice were accompanied, in most cases, by increases in the frequency of errors.

202. POSNER, M. I., "Information Reduction in the Analysis of Sequential Tasks." *Psychological Rev.*, Vol. 71 (1964) pp. 491-504.

This paper proposes a taxonomy of information-processing tasks. Information-conserving, -reducing, and -creating operations are viewed as different methods of processing. The main concern of this paper is information reduction; it is suggested that this represents a kind of thinking in which the solution is in some way implicit in the problem, but in which the input information must be reflected in a reduced or condensed output. A number of tasks within the areas of concept identification and utilization are shown to have this character. If the tasks require complete representation of the stimulus in the response (condensation), the amount of information reduced is directly related to difficulty, both during learning and in utilization of previously learned rules. If the tasks allow the subjects to ignore information in the stimulus (gating), the direct relation between reduction and difficulty is found during learning but may not occur after the rule is learned.

203. SMITH, E. E., "Choice Reaction Time: An Analysis of the Major Theoretical Positions." *Psychological Bull.*, Vol. 69 (1968) pp. 77-110.

This report analyzes and evaluates (against experimental findings) contemporary theories of choice reaction time (CRT). The influence of Donders' subtraction method on current theory is assessed, and experimental findings are reviewed that are concerned with the effects on CRT of (1) number of alternatives, (2) stimulus probability, (3) stimulus value, (4) repetition of stimulus or response, (5) stimulus discriminability, (6) stimulus-response compatibility, (7) practice, and (8) emphasis on speed vs accuracy. A three-state conceptualization of the central mechanisms operative during the latent period (stimulus preprocessing, stimulus categorization, and response selection) is proposed. The theories are dichotomized on the basis of the process—template matching vs feature testing—which is assumed to underlie stimulus categorization. The analysis indicates that current theories have neglected response-selection processes and consequently are unable to account for several experimental findings. A final section deals with the relation of CRT theories to perceptual recognition theories.

204. SMITH, S. L., and THOMAS, D. W., "Color vs. Shape Coding in Information Displays." *J. Applied Psychology*, Vol. 48, No. 3 (1964) pp. 137-146.

This study is an examination of usefulness of color as non-redundant code and a comparison of color with other possible visual coding dimensions, particularly shape coding. As compared in a counting task, color coding was independent of shape coding on which it was superimposed, and color coding was dominant in visual separability.

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206. ALLUISI, E. A., MULLER, P. F., JR., and FITTS, P. M., "An Information Analysis of Verbal and Motor Responses in a Forced-Paced Serial Task." *J. Exp. Psychology*, Vol. 53 (1957) pp. 153-158.

207. ALLUISI, E. A., STRAIN, G. S., and THURMOND, J. B., "Stimulus-Response Compatibility and the Rate of Gain of Information." *Psychonomic Science*, Vol. 1 (1964) pp. 111-112.

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217. BROADBENT, D. E., "Listening to One of Two Synchronous Messages." *J. Exp. Psychology*, Vol. 44 (1952) pp. 51-55.

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220. CONRAD, R., "Missed Signals in a Sensorimotor Skill." *J. Exp. Psychology*, Vol. 48 (1954) pp. 1-9.

221. CONRAD, R., and HILLE, B. A., "Self-Pacing Performance as a Function of Perceptual Load." *J. Exp. Psychology*, Vol. 53 (1957) pp. 52-54.

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COST EFFECTIVENESS—GENERAL METHODOLOGY

300. FISHER, G. H., *The Role of Cost-Utility Analysis in Program Budgeting.* The RAND Corp., RM-4279-RC (DDC No. AD 608055) (Sept. 1964) 39 pp.

Cost-utility analysis pertains to the systematic examination and comparison of alternative courses of action that might be taken to achieve specified objectives for some future time period. The primary purpose of cost-utility analysis is usually not to "make" the decision, but rather to sharpen the intuition and judgment of the decision maker. This memorandum outlines the main characteristics of cost-utility analysis and some of the major considerations involved in carrying out such analyses. In addition, two illustrative examples are presented to help add content to discussion of principles contained in the initial sections of the paper.

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COST EFFECTIVENESS—HIGHWAY IMPROVEMENT PROJECTS

348. Roy Jorgensen and Associates, Westat Research Analysts, *Evaluation of Criteria for Safety Improvements on the Highway.* Report to the U.S. Dept. of Commerce, Bur. of Pub. Roads, Office of Highway Safety (1966).

The report presents recommended methods for identifying hazardous locations, forecasted accident reductions for various types of safety improvements, and methods for determining the cost effectiveness of proposed safety improvements. It discusses accident records systems organization and needs, improvement failures, and spot improvements vs overall highway improvement.

349. Arthur D. Little, Inc., *Cost-Effectiveness in Traffic Safety.* Praeger (1968).

To achieve significant reductions in the staggering toll of traffic accidents, major commitments of resources and effort are required. The gravity of the responsibility for allocating support wisely among the possible safety programs demands that decisions be based on systematic consideration of the relevant evidence. Because the basic purpose of cost-effectiveness analysis is to assist decision makers in that process, this study was to assess the feasibility of applying such treatment to the evaluation of traffic safety programs.

This report describes the background for the study

project, summarizes the principal findings, and discusses the three major topics: analysis, data, and measurements. An annex contains a more extended treatment of certain topics introduced in the main report. Included here are a survey of optimization techniques, a pilot study evaluating remedies for cross-median collisions, a review of the adequacy of traffic safety data in various program categories, and a set of examples dealing with measurement problems. (Author)

350. MOHRING, H., and HARWITZ, M., *Highway Benefits: An Analytical Framework.* Northwestern Univ. Press (1962).

The study deals with the nature and measurement of highway benefits and how their magnitude and distribution are affected by alternative financing systems. Its basic objective is to answer five broad questions: (1) How do the benefits of highway investment arise? (2) How can these benefits be measured in both principle and practice? (3) What are the mechanisms by which these benefits are distributed to individual members of the population? (4) What effects does the financing system adopted for highway improvements have on the magnitude and distribution of benefits? (5) To what extent can the existing body of research on the economic impact of highways be used to provide quantitative estimates of *net* highway benefits? (Author)

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363. GREENSHIELDS, B. D., "Quality of Traffic Transmission." *Proc. HRB,* Vol. 34 (1955) pp. 508-522.

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369. SMITH, G. W., "Benefit-Cost Ratios: A Word of Caution." *Hwy. Res. Record No. 12* (1963) pp. 77-81.

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MISCELLANEOUS

376. CRIBBINS, P. D., and SUMMER, G. S., *The Correlation of Accident Rates With Geometric Design Components of Various Types of Highways.* Engineering Research Dept., Univ. of North Carolina (June 1964) 70 pp.

This study is a detailed investigation of accidents occurring at median openings or crossovers between intersections on rural divided highways without control of access. All of the accidents were analyzed according to the type of occurrence and the pattern of maneuver the vehicles were making. Accidents involving commercial vehicles were analyzed separately. It was found that a quarter of all accidents occurring between intersections on a four-lane divided highway were happening at the median opening. The report recommends the installation of left-turn slots at these sites.

377. PERKINS, S. R., and HARRIS, J. I., *Traffic Conflict Characteristics; Accident Potential at Intersections.* General Motors Research, Pub. GMR-718 (1967).

Traffic Conflict Characteristics are measures of traffic accident potentials. A traffic conflict is any potential accident situation. More than 20 objective criteria for traffic conflicts (or impending accident situations) have been defined to specific accident patterns at intersections: essentially, these traffic conflicts are defined by the occurrence of evasive actions, such as braking or weaving, that are forced on a driver by an impending accident situation or a traffic violation. A method of systematically observing an intersection for traffic conflicts has been devised. In three 12-hr observation sessions, it is possible to evaluate completely an intersection; the information obtained is much more comprehensive than that normally available from accident histories. Further, the initial causes of the incidents, which accident records often fail to reveal, are uncovered. Traffic conflict studies use objective criteria to obtain significant quantities of data in short observation periods.

378. ROCKWELL, T. H., ERNST, R. L., and RULON, M. J., "Visual Requirements in Night Driving." *NCHRP Report 99* (1970).

This report presents basic information on the visual requirements of night driving and on the results of night driving under severe visual degradation. Also presented are the results of basic research employing a specially constructed eye marker camera that indicates what the driver sees.

379. GOELLER, B. F., *Modeling the Traffic-Safety System.* Memo. RM-5633-DOT, The RAND Corp. (Apr. 1968).

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381. KAY, J. L., "Signal System Studies: A New Approach." *Traffic Engineering,* Vol. 40, No. 4 (Jan. 1970) pp. 24-31.

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384. CANARD, A. F., ET AL., *Automobile Accident Costs and Payments—Studies in the Economics of Injury Reparation.* Univ. of Michigan Press (1964).

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386. TAYLOR, W. C., "Speed Zoning: A Theory and Its Proof." *Traffic Eng.,* Vol. 35, No. 4 (Jan. 1965).

APPENDIX W

OTHER AGENCIES CONTRIBUTING TO THIS RESEARCH STUDY

Agencies Visited on Current Practices Surveys

Arizona, State Highway Department
California, Department of Public Works, Division of Highways
Colorado, Department of Highways
Florida, Department of Transportation
Michigan, Department of State Highways
Montana, State Highway Commission
New Hampshire, Department of Public Works and Highways
North Carolina, State Highway Commission
Ohio, Department of Highways
Pennsylvania, Department of Transportation
Texas, State Highway Department
United Kingdom, Road Research Laboratory

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5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80
8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20

* Highway Research Board Special Report 80.

Rep. No.	*Title*
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
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