# DEVELOPMENT OE INFORMATION REQUIREMENTS AND TRANSMISSION TECHNIQUES FOR HIGHWAY USERS 

## HIGHWAY RESEARCH BOARD 1971

## Officers

CHARLES E. SHUMATE, Chairman
ALAN M. VOORHEES, First Vice Chairman
william l. garrison, Second Vice Chärman
W. N. CAREY. JR., Executive Director

## Executive Committee

F. C. TURNER, Federal Highway Administrator, U. S. Department of Transportation (ex officio)
A. E. JOHNSON, Executive Director, American Association of State Highway Officials (ex officio)

ERNST WEBER, Chairman, Division of Engineering, National Research Council (ex officio)
OSCAR T. MARZKE, Vice President, Fundamental Research, U. S. Steel Corporation (ex officio, Past Chairman, 1969)
D. GRANT MICKLE, President, Highway Users Federation for Safety and Mobility (ex officio, Past Chairman, 1970)

CHARLES A. BLESSING, Director, Detroit City Planning Commission
HENDRIK W. BODE, Professor of Systems Engineering, Harvard University
JAY W. BROWN, Director of Road Operations, Florida Department of Transportation
W. J. BURMEISTER, State Highway Engineer, Wisconsin Department of Transportation

HOWARD A. COLEMAN, Consultant, Missouri Portland Cement Company
HARMER E. DAVIS, Director, Institute of Transportation and Traffic Engineering, University of California
WILLIAM L. GARRISON, Professor of Environmental Engineering, University of Pittsburgh
george e. holbrook, E. I. du Pont de Nemours and Company
EUGENE M. JOHNSON, President, The Asphalt Institute
A. SCHEFFER LANG, Department of Civil Engineering, Massachusetts Institute of Technology JOHN A. LEGARRA, State Highway Engineer and Chief of Division, California Division of Highways
WILLIAM A. McCONNELL, Director, Operations Office, Engineering Staff, Ford Motor Company
JOHN J. McKETTA, Department of Chemical Engineering, University of Texas
J. B. McMORRAN, Consultant

JOHN T. MIDDLETON, Acting Commissioner, National Air Pollution Control Administration
R. L. PEYTON, Assistant State Highway Director, State Highway Commission of Kansas

MILTON PIKARSKY, Commissioner of Public Works, Chicago, Illinois
CHARLES E. SHUMATE, Executive Director-Chief Engineer, Colorado Department of Highways
DAVID H. STEVENS, Chairman, Maine State Highway Commission
ALAN M. VOORHEES, Alan M. Voorhees and Associates

## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Advisory Committee
CHARLES E. SHUMATE, Colorado Department of Highways (Chairman`
ALAN M. VOORHEES, Alan M. Voorhees and Associates
WILLIAM L. GARRISON, University of Pittsburgh
F. C. TURNER, U. S. Department of Transportation
A. E. JOHNSON, American Association of State Highway Officiais

ERNST WEBER, National Research Council
OSCAR T. MARZKE, United States Steel Corporation
D. GRANT MICKLE, Highway Users Federation for Safety and Mobility
W. N. CAREY, JR., Highway Research Board

General Field of Traffic
Area of Operations and Control
Advisory Panel G3-12
HAROLD L. MICHAEL, Purdue University (Chairman)
JOHN E. BAERWALD, University of Illinois
SIEGFRIED M. BREUNING, Social Technology Systems, Inc.
JOHN FREELAND, Highway Systems Consultant
RICHARD W. ROTHERY, General Motors Research Laboratory
FRED C. TARBOX, Ohio Department of Highways
WAYNE N. VOLK, Wisconsin Division of Highways
EUGENE JOHNSON, III, Federal Highway Administration
ASRIEL TARAGIN, Federal Highway Administration
K. B. JOHNS, Highway Research Board

Program Staff
K. W. HENDERSON, JR., Program Director
L. M. MacGREGOR, Administrative Engineer
W. C. GRAEUB, Projects Engineer
J. R. NOVAK, Projects Engineer
H. A. SMITH, Projects Engineer
W. L. WILLIAMS, Projects Engineer

HERBERT P. ORLAND, Editor
ROSEMARY S. MAPES, Editor
CATHERINE B. CARLSTON, Editorial Assistant

# FOREWORD 

By Staff

Highway Research Board

This report will be of special interest to traffic engineers, traffic sign manufacturers, information scientists, and human factors experts interested in the information requirements of the highway user and, in particular, improved information transmission techniques involving the use of traffic signs. This research defines and measures, where possible, all pertinent factors and functions of the information system. With regard to the highway user, the research includes those parameters that motivate the driver to respond naturally and safely to the range of messages transmitted and attempts to identify the capacity of drivers to assimilate varying amounts of information.

Street and highway sign standardization has progressed to a satisfactory point in many of its technical aspects, but many functional deficiencies remain. The Interstate Sign Manual incorporates many appropriate provisions for particulars of design and application, but, with the ever-increasing demands of the driving task, there is urgent need for improvement in the understanding of the driver's needs for information and the means of communicating it to him. Better performance criteria must be established for selection and transmission of the appropriate messages. It was with these thoughts in mind that this project was initiated during the fall of 1966.

The objective of the over-all research problem was development of a welldefined information system for the highway user that will represent all conditions with which the driver is routinely, occasionally, and rarely confronted.

Airborne Instruments Laboratory, a division of Cutler-Hammer, addressed itself in this research to the question: "What information is needed by highway users for safe, convenient, efficient, and comfortable performance of the driving task?" The systematic approach used to determine the nature of the information needed by highway users provided a framework for conceptualizing the form, and content, and timing of information so that it can be used most effectively by drivers.

A body of information needs has been identified, the satisfaction of which enables drivers to perform the driving task safely, conveniently, efficiently, and comfortably. Principal factors have been defined that organize the information needs into functional groups, delineate the interactions between the information needs, and identify the criteria for selecting and transmitting information so that the drivers' needs are satisfied.

It was found that a demanding priority (called primacy) exists in satisfying information needs relating to the basic tasks of tracking and speed control (called microperformance) having priority over the information needs relating to driver response to road and traffic situations (called situational performance). Information needs relating to direction finding and trip planning (called macroperformance) rank lowest in this hierarchy. Satisfying this primacy of information needs is basic to the design of a highway information system. Expectancy, another key factor
in the performance of the driving task, has been defined so that the driver can be provided with information about what directional information he should expect in transit, when to expect it, and what it should look like.

Included in the report is a draft procedure that can be applied to Interstate and rural arterial highways to permit the systematic application of pertinent human factor principles to the review of information system designs. This draft procedure is presented in the form of a "Manual on Information System Review Procedures," which is included as Appendix H . This manual, in addition to an iterative formal procedure that can be used for the review of proposed signing plans, contains a section in which human factors principles useful to the traffic engineer are abstracted and defined.

The role of signs in a highway information system, as well as several aspects important in the design and use of fixed highway signing, is also included. Detailed attention has been given to the design of signs for night legibility, and a computer program was developed and employed to determine the night legibility of signs and the variation of legibility with variations in environmental and geometric parameters. Conclusions are drawn concerning the adequacy of sign design criteria contained in present manuals. The possibility of blockage of signs by trucks has been modeled mathematically and the effect of lateral displacement of signs on letter height has been analyzed.

Recommendations are made for future research that could include additional studies design to apply, modify, and validate the "Information System Design Procedures"; develop uniform mapping practices that will complement the highway information system concept; and develop improved sign design procedures covering such aspects as optimum arrangement of message, symbolic versus schematic signing, and letter design details.

## CONTENTS

SUMMARY
PART 1
Chapter one Introduction and Research Approach Drivers' Information Needs and Their Satisfaction
Fixed Highway Signing
Terminology
Organization of Report
Chapter two Findings-Drivers' Information Needs and Their Satisfaction
Highway Users' Information Needs
Satisfaction of Information Needs
Chapter three Findings—Fixed Highway Signing
Sign Design for Night Legibility
Blockage of Signs by Trucks
Effects of Lateral Sign Displacement
Chapter four Applications and Implications
In-Trip Sources
Pretrip Sources
Procedural Changes and Phasing
chapter five Conclusions and Suggested Research Drivers' Information Needs and Their Satisfaction
Fixed Highway Signing
REFERENCES

PART II
appendix a Details of Task Analysis and Other Analytic Procedures
appendix b Description of Test Site
appendix c Computer Program Description-Program ROADSIGN
appendix d On Detecting the Absence of Information Need Satisfaction

APPENDIX E On the Satisfaction of Macroperformance Information Needs
appendix F Survey of Possible Aiding Techniques
appendix g Current Mapping Practices
appendix H Notes for a Manual on Information System Review Procedures

## ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 3-12 by Airborne Instruments Laboratory, a division of Cutler-Hammer, with Gerhart F. King as Principal Investigator. He was assisted throughout the project by H. Lunenfeld, and for all but the last six months of the project by G. J. Alexander." The latter played a principal role in the conduct of the research, especially as regards the human factors portions of the study. In addition to the named authors, and the named authors of the various appendices, Dr. P. Abramson and Messrs. B. Adler and R. Varady are responsible for significant portions of this report. Other present and former members of the technical staff of AIL who contributed to this research effort were D. Glazer, J. Martin, L. Small, E. Varassi, M. Warskow, and J. Woo.

Grateful acknowledgment is made of the guidance and assistance provided by Dr. T. M. Allen of Michigan State University and Dr. A. L. Straub of Clarkson College of Technology, who acted as consultants throughout the entire study program.

In the performance of this study several individuals in various parts of the United States have given freely of their cooperation and assistance. Included in this group were the following:
J. Boysen, American Automobile Association,
A. Johnson, Executive Director, American Association of State Highway Officials.
A. R. Pepper, AASHO Special Subcommittee on Interstate Sign Manual Changes.
P. C. Petrillo, Automobile Club of New York.
C. Robinson, Automotive Safety Foundation (now Highway Users Federation for Safety and Mobility).
V. J. Richey, Division of Bay Toll Crossings, California Department of Public Works.
D. S. Luethje, California Highway Patrol.
P. Athol, Chicago Expressway Surveillance Project.

Dr. J. A. Ciccolella, Signal Products Division, Elastic Stop Nut Corp.
E. Farber, Franklin Institute Research Laboratory.
G. E. Meese, Miniature Lamp Dept., General Electric Co. W. G. Trabold, General Motors Research Laboratory.

* Currently with the Office of Traffic Operations, Federal Highway Administration.
P. S. Meyer, Automotive Safety Engineering, General Motors.
R. Moore, Peconic River Airport, Grumman Aircraft Corp.
G. Onhsen, Guidelamp Co.
K. McCasland, Gult Freeway Surveillance Project.
R. Hostetter and D. Mace, HRB Singer, Inc.
H. Davis, A. D. May, D. Finch, W. Humberger, D. Horning, R. Horonjeff, N. Kennedy, and W. Snowden, Institute of Transportation and Traffic Engineering, Berkeley, Calif.
J. O. Elstad and H. Woltman, Reflective Products Div., Minnesota Mining and Mfg. Co.
S. M. Breuning, Massachusetts Institute of Technology.
C. A. Douglas, National Bureau of Standards.
J. Lema, National Joint Committee on Uniform Traffic Control Devices.
H. L. Crane, National Proving Ground for Freeway Surveillance Projects.
T. Chodosh, Motor Vehicle Inspection Div., New Jersey Div. of Motor Vehicles.

Philco Ford Corp.
Rand McNally.
R. Dunn, Seattle Expressway Surveillance Project.

Thanks also are extended for the assistance given in the determination of current signing problems and practices by the state highway departments of California, Colorado, Florida, Illinois, Kansas, Maine, Maryland, Michigan, New Jersey, New Mexico, New York, North Dakota, South Carolina, Tennessee, Texas, Virginia, Washington, and Wyoming.

Also acknowledged are the time and effort freely given by J. C. Bullock, Jr., S. F. Hulbert, J. Lema, and R. Michaels, who reviewed and critiqued the preliminary research findings.

Last, but certainly not least, acknowledgment is made of the deep debt of gratitude owed the North Carolina State Highway Commission, under W. F. Babcock, State Highway Administrator. Special thanks are due to M. R. Sproles, State Planning and Research Engineer, and to J. O. Litchford, State Traffic Engineer. Without the full-hearted cooperation of these individuals, their assistants, and other staff members, the application and validation phase of this project would have been impossible.

# DEVELOPMENT OF INFORMATION REQUIREMENTS AND TRANSMISSION TECHNIQUES FOR HIGHWAY USERS 


#### Abstract

SUMMARY A team of engineers and psychologists studied drivers' information needs and the means of satisfying them. Through the technique of task analysis, a body of information needs was identified, the satisfaction of which enables drivers to perform the driving task safely, conveniently, efficiently, and comfortably. Principal factors were defined that organize the needs into functional groups, delineate the interactions between them, and identify the criteria for selecting and transmitting needs to be satisfied.

Analysis of the driving task disclosed that the operations that a driver performs can be characterized in terms of a hierarchy. The basic tasks of tracking and speed control (called microperformance) are at one end of the hierarchy, driver responses to road and traffic situations are in the middle; and direction finding and trip planning (called macroperformance) are at the other end. Driver information needs were arranged in accordance with this hierarchy. A demanding priority (primacy) exists in satisfying information needs, with micro needs having priority over situational and macro needs. Satisfying this primacy of information needs is basic to the design of a highway information system.

Another key factor in the performance of the driving task is expectancy. When a trip is planned, the driver forms expectations of the conditions to be encountered in transit. Expectations are also formed while driving, regarding roads, signs, services, etc. These expectations operate in such a manner as to provide the driver with a basis for planning his trip, and to provide him with information about what directional information he should expect in transit, when to expect it, and what it should look like.

On the basis of these principles, as applied to actual sections of Interstate and rural arterial highways, a procedure was developed to permit the systematic application of pertinent human factors principles to the review of information system designs. The procedure was formalized in "Notes for a Manual on Information System Review Procedures" (Appendix H). This manual, in addition to containing an iterative formal procedure that can be used for the review of proposed signing plans, contains a section in which human factors principles that are useful to the traffic engineer are abstracted and defined.


## Role of Signs

The role of signs in a highway information system, as well as several aspects important in the design and use of fixed highway signing, was analyzed in detail. It was found that signs could, and should, continue to be the main information carriers.

Detailed attention was paid to the design of signs for night legibility. A com-
puter program was developed to determine night legibility of signs and the variation of legibility with variations in several important parameters. The program was used to analyze existing signs on a stretch of I-85 in North Carolina.

Conclusions were drawn concerning the adequacy of sign design criteria contained in existing manuals. It was found that legibility of signs varies greatly with apparently minor changes in approach horizontal and vertical alignment. It was also found that overhead signs are inadequate if illuminated by only the low-beam headlamps of an approaching vehicle.

The possibility of blockage of signs by trucks was modeled mathematically and, under certain conditions, it was found that this potential blocking could represent a serious problem in the proper reception of information by drivers.

The effect of lateral displacement of signs on required letter height was analyzed and it was found that considerable increases in required letter height may be required if signs are offset, as recommended, to create clear recovery areas.

## Other Areas Covered

Other areas covered include the following:

1. A simulation of the probability of detecting driver "confusion" by measuring parameters of the traffic stream. Only gross changes in driving behavior, by an appreciable portion of the total traffic, could be detected by such means.
2. The basic principles derived were applied to the specific problem of presenting directional information. The concept of serving all drivers legally on the road leads to the conclusion that it is impossible to give complete directional information to all potential destinations while en route. Emphasis is therefore placed on the construction of a trip plan that becomes part of the driver's a priori knowledge. Thus, the role of the macro (directional) information system is to serve as a validity check on the trip plan and a means to implement it. This should be achieved by concentrating on clear, unequivocal identification of highway links by designation and direction. The various existing and potential means of doing this, via the visual channel, are discussed, and a consistent system of macro information transmission, analyzing all factors affecting the what, where, and how of presenting this information, is developed.
3. Possible supplementary techniques, using technologies other than fixed signing and/or transmission and reception of information on other than the visual channel, were evaluated in terms of their potential for satisfying each type of information need and in terms of the type of in-vehicle and on-highway equipment that would be required.
4. Current mapping practices were analyzed to determine the ability of available maps to satisfy drivers' information needs. Considerable improvements in map standardization and usability are possible. Too little is known concerning the ability of drivers, on a population basis, to use maps properly and to derive the desired information from them.

Suggestions for further research include:

1. Additional validation and codification of the "Information System Review Manual" (Appendix H).
2. Development of the sign legibility computer program to develop a handbook of nomographic solutions to sign design problems.
3. Extension of the truck blockage model to observed distributions and validation and calibration of the model.
4. Development of uniform mapping practices and studies of the population map-reading skill level.
5. Specific problems of sign design.
6. Human factors studies on information-processing capability.
7. Aiding techniques for situational performance.
8. Aiding techniques for alternate routing.
9. Studying improved means for advising drivers of unusual or unexpected conditions.

## INTRODUCTION AND RESEARCH APPROACH

## DRIVERS' INFORMATION NEEDS AND <br> THEIR SATISFACTION

This study was authorized because, according to the NCHRP Project 3-12 Project Statement,
[W]ith the ever-increasing demands of the driving task, there is urgent need for improvement in the understanding of the driver's needs for information and the means of communicating it to him.
The importance of providing the driver with the information that he needs to perform the driving task has been pointed out by Cumming (1) who states:
[T]he road complex must provide for the operator a comprehensive display of information both in the formal sense of signs, signals, guidelines and edge posts, and in the informal sense of clear visibility in all relevant directions. Design and placement of these formal displays must be compatible with the prevailing vehicle speeds, traffic pattern, and visual and response characteristics of the human operator; moreover, they must be free of irrelevant distracting material, either man made or natural, or if this is not possible, should be able to function in spite of competing demands for attention.

Specific parts of the existing information system have recently been the subject of criticism. According to the Automobile Club of New York (2), ". . . far too many signs remain obsolete, confusing, inadequate or deceptive." "If the sign system fails, the whole highway design fails" (3).

That poor signing is a major source of annoyance to the driver is shown in a study by Kuprijanow et al. (4) where, in response to a nationwide motorist questionnaire survey, more than 60 percent of the respondents indicated "confusing and inadequate signs" to be the most or next most annoying out of six alternate choices. Signs, however, are not the driver's only source of information. The subject of adequacy of information pertains to all information the driver needs to perform his task-that is,
information about the vehicle, the road, traffic, the destination, and service.

Future highway system developments are likely to increase the importance of the communications system. By 1985, more drivers will be driving more cars on more miles of highway than they are today.* It is logical to assume that without improvement in the system, the trend of rising traffic fatalities and injuries will continue, and the number of drivers lost, confused, and otherwise irritated (as yet unmeasured quantities) will increase.

The objective of the over-all research program is the development of a well-defined information system for the highway user. Answers are needed for the following questions:

1. What information is needed by the highway users for their safe, convenient, efficient, and comfortable performance of the driving task?
2. What are the principal factors and interactions underlying the selection and transmission of this information?
3. To what extent can visual communications be used successfully?
4. Are supplemental communication techniques needed? If so, where and how could they be applied effectively?

This project was directed to deal with (but was not limited to) questions 1 through 3 . It has done this and has treated question 4 to some extent.

## System Elements

The information requirements of the highway user exist within a system of clearly defined elements: a driver operating a vehicle on a highway within an environment.

Attributes of these elements are analyzed with regard to the manner in which they influence the generation, transmission, and receipt of information.

## Driver

The driver is an important element in the highway system, as indicated by the estimate that driver error contributes to 80 to 90 percent of all accidents (7). Because the purpose of the highway system is the safe, comfortable, convenient, and efficient movement of goods and people, any system element responsible for a large percentage of system failure deserves close scrutiny.

The driver is the main controlling element in the highway system; his ability to perform within the system determines the system's ability to perform its intended function. It must be noted that a breakdown in safety may not be the only system failure; breakdowns in the other three criteria, although not necessarily catastrophic, also indicate system failure. A lost driver typifies this kind of failure.

The characteristics of the driver are given in the Traffic Engineering Handbook (8) and in Matson et al. (9). These findings are supplemented by describing the range of driver characteristics found on the highway.

Data from two sources (10,11) indicate that almost 90 percent of persons over 16 years old are licensed drivers. Because the driving population is drawn from the over-all population and is an overwhelming part of it, it can be assumed that the two populations are similar in many psychological and physical attributes. An investigation of licensing requirements indicated that because minimum standards are set for vision and literacy, and some percentage of the population could not meet these standards, the distribution of the population for these characteristics differs at the low end. Some generalizations can be made about median and worst-case drivers. Median is defined as that point in a distribution that divides the range of values into two equal parts. Worst case is defined as less than 5 percent of the population.

1. Age.-The median age is 38 . The range is from 14 to over $70 ; 14$ and over 70 represent the worst case.
2. Sex.-Because 58 percent of all drivers are male, the median driver is male.
3. Intelligence.*-The median IQ is 100. The range is from 70 to over 150 . Worst case is below 85 .
4. Education.-The median education is 10.5 years of formal education. Worst case is less than 4 years.
5. Visual Acuity.-Median visual acuity is $20 / 20$. Worst case about 20/70 to 20/100.
6. Driving Exposure.-A study by Kuprijanow et al. (4) indicates medial mileage to be between 9,000 and 12,000 miles per year.
There are several differences between the driving population of today and the anticipated population of 1980.

Education.-The Statistical Abstracts (11) show that the median adult possesses a tenth-grade education level.

[^0]However, the trend is toward a higher level in the future. This is shown by the fact that the data for tenth-grade educational level were based on individuals over 25 (1960 data). It was found that among 17 -year-olds, 76 percent are still in school. This points to a higher average education level for future drivers.

Age.-Analysis of the data indicates that the under-25 age group has the highest percentage of licensed drivers; therefore, as the percentage of young people increases, the percentage of young drivers will increase. An increase in the number of older drivers is expected as average life span increases and more retired couples travel.

Unfamiliar and Foreign Drivers.-Average trip length will increase, largely because of improved comfort and convenience in driving and increased recreational travel promoted by rising income and leisure time. The efforts of governmental and private agencies to foster tourist travel in the United States, combined with the rising standard of living in the Western world, will result in a greater number of tourists with a fragmentary knowledge of English driving on the highways. This will be most apparent in areas adjoining Mexico and the Frenchspeaking parts of Canada, as well as in the major metropolitan areas.
Summary.-These are but a few of the factors that affect the driver. How these factors are understood and used will play a large role in the efficiency with which the system operates. Human-factors engineers find greater safety and efficiency in any system operation when it is designed to use existing user capacities and limitations than when these properties are considered only peripherally or not at all (12). If the highway system is to fulfill its intended function, the full range of user characteristics and attributes must be an integral part of the design process:

Design Driver Characteristics.--It is usually impossible to accommodate all cases at all times so that a firstpercentile case is virtually ruled out. The tradeoff usually accepted in human factors engineering is to accommodate the fifth percentile. This is the recommendation offered herein; that is, the so-called "worst-case" driver will be the one with fifth-percentile attributes. This fifth-percentile criterion is not necessarily a hard and fast rule to be followed, because designing a system based on a fifthpercentile driver may lead to a technically unfeasible or economically impractical system. However, the designer must bear in mind that the population of drivers is heterogeneous and includes drivers who are worst cases. Therefore, the information system must accommodate as many drivers as possible, at all times, under all conditions, rather than only the median driver and under median conditions.

Organismic Attributes.-Organismic attributes are attributes whose distributions are relatively fixed within the population and include such factors as age and sex. Of all driver attributes, age appears to be the one that correlates most highly with most of the physically attributable worst cases. The older driver is generally worse in terms of reaction time (8), visual acuity (13), vigilance (14), glare sensitivity (13), and hearing (15). However, he
seems to compensate for his deficiencies by his experience and more realistic self-pacing attributes (16). The designer must consider older drivers, especially in view of the trend toward older drivers being on the road more and more. This is especially true in retirement areas (e.g., St. Petersburg, Fla.). Although age itself is not necessarily a worst-case attribute, the high correlation between age and worst-case attributes indicates that the age of drivers is a good index of worst case.

Processing Attributes.-

1. A priori knowledge.-Because a priori knowledge plays an important part in processing information, it can be seen that lack of a priori knowledge is a worst-case attribute. It is almost impossible to define a worst-case driver in terms of a priori knowledge except in terms of his driving experience. Because the younger driver is likely to have the least experience, it is conceivable that a fifth-percentile driver, in terms of driving experience, falls in the fifth percentile in terms of age (under 16 years). The younger driver, lacking in experience, is probably also the worst case in terms of his self-pacing attributes and may not have learned how to load-shed (shift attention) efficiently.
2. Processing capacity.-Individual channel capacities vary greatly among individuals. However, the decisionmaking capacity is $7 \pm 2$ equiprobable responses. Assuming the two as one standard deviation, it can be seen that the fifth percentile (represented by -2 standard deviation units) is about 3 equiprobable responses.

Hulbert (14) has shown that vigilance is greatly affected by age, so that the fifth-percentile driver in terms of age ( 70 years) is fifth percentile in terms of vigilance. As he points out, the aged driver initially is as vigilant as the young driver. However, the aged driver is unable to maintain a high level of vigilance for an extended period of time. This, evidently, should affect the design for system external pacing.
3. IQ.-Although it is impossible to quantify the effects of IQ on information processing, it seems that drivers with low IQ's (that is, 70 IQ points) are probably deficient in making complex decisions and efficient load-shedding.
4. Education.-A final worst case is in terms of education and literacy. Worst-case drivers have educational levels below fifth grade (11), and therefore may not be able to read or comprehend complex messages.

## Reception Attributes.-

## 1. Visual channel.-

a. Visual acuity.-Visual acuity is the first worstcase attribute. $20 / 70$ is the fifth-percentile worst case, although Hulbert (14) believes that 20/100 is more realistic.
b. Accommodation and convergence.-Another worst-case attribute also related to age is accommodation and convergence (the act of aiming both eyes at the same point). Not only does it take the older driver longer to accommodate from a near to a far object, but also, as he ages, he is unable to converge on near objects. Schmidt and Connolly (13) suggest that older drivers have
trifocals to enable them to see their in-vehicle displays.
c. Glare sensitivity.-Another age-related worst case is glare sensitivity, with older drivers taking up to three times as long to recover from glare as the younger driver.
d. Color weakness and blindness.-A final visual worst case, non-age-related, is color weakness and blindness, with approximately 8 percent of male drivers and 0.5 percent of female drivers either color-weak or color-blind (13).

The worst-case driver thus exhibits some color weakness and, because no color alphabet can be devised that will satisfy all color-blind or color-weak drivers, the most that can be done is to aid these drivers through redundancy.
2. Auditory channel.-The most obvious worst case is deafness. According to Hulbert (14) approximately 5 percent of the driving population ( 40 percent of those older than 65 years) have impaired hearing, with an additional 0.1 percent being totally deaf. Thus, although the absolute worst-case driver is totally deaf, the fifth percentile has impaired hearing. Because 40 percent of drivers with impaired hearing are older than 65 , it is probable that their frequency response is impaired because there is much loss in high-frequency response ( 2 kc ) sensitivity in the over- 40 age group (almost 40 decibels loss at 3 kc to more than 50 dB loss at 7 kc ) (12). This suggests that tones of greater than 2 kc should not be used in auditory systems.

## Vehicle

## Intravehicular Communication.-

Vehicle Performance.-The most elemental vehicle characteristics are acceleration and deceleration. The former is fundamentally a function of the vehicle's power-toweight ratio and the latter is a function of its brakes. Considerable variation is possible as a function of driver ability, quality and condition of tires, surface condition, weather, etc.

Because of the numbers involved, the power-to-weight ratio is generally expressed as pounds per horsepower, which ranges from about 13 to $30 \mathrm{lb} / \mathrm{hp}$.* Extreme values of $7.7 \mathrm{lb} / \mathrm{hp}$ to more than $40 \mathrm{lb} / \mathrm{hp}$ have been noted. The importance of the weight/power ratio becomes readily apparent in considering the effect of adding passengers to different vehicles. Adding three passengers (assuming each to weigh 140 lb ) to a heavy car increases its weight/ power ratio from 15 to about 16 ; adding the same amount to a light car increases its comparable figure from 36 to nearly 44 . Thus, all other things being equal, the accelerating ability of the heavier car is decreased approximately 7 percent, whereas that of the lighter car is decreased by more than 20 percent. This is an important consideration affecting all decisions that depend on acceleration. Without being aware of the figures involved, the driver must

[^1]know how his vehicle will perform in varying situations. He obtains this knowledge through experience.

The vehicle's braking ability is similarly related to many variables. However, given two vehicles, with all other factors equal, the stopping ability of each is somewhat relatable to the number of square inches of brake swept area available to convert kinetic energy of the vehicle's motion into thermal energy (heat). For most U.S.-made cars, the actual values range from about 10 to $15 \mathrm{lb} / \mathrm{sq} \mathrm{in}$.

As in the case of acceleration, the driver obtains information about his brakes by experience and through kinesthetic and tactile sensing, such as increased pressure to achieve the same rate of deceleration. However, in the case of power brakes, this is largely masked (compensated for) by the power-assist unit. In addition, he may receive audible warning (squeal) from his tires.

Again, the driver must realize that increasing the load of his vehicle will affect its ability to decelerate. This does not necessarily result in longer stopping distances, but requires increased brake pressure to stop in the same distance.

Automotive Equipment, Power Assists, Etc.-The most common automatic devices on U.S. cars are automatic transmissions, power steering, and power brakes.

1. Automatic transmissions.-Automatic transmissions are the most popular devices, being found on more than 90 percent of the vehicles produced in 1969.

Provided that the automatic transmission is functioning normally, there is no need for the driver to know or understand what it is doing and no direct information is given to him. Nevertheless, a perceptive driver will sense varying engine speed relative to vehicle speed and may deduce (for example) that it shifted. However, when the automatic transmission does not operate properly, the driver may not perceive this condition or diagnose it as a transmission problem. Again, there is no direct information given to the driver in existing cars to warn him of trouble. Therefore, it is suggested that instruction on the symptoms of faulty automatic transmission operation should form a part of the driver's basic education.
2. Power steering.-Power steering is the next most popular power accessory. About 84 percent of 1969 U.S. automobiles were equipped with power steering, and the percentage has been steadily increasing. The various systems in use offer varying degrees of "road feel" to the driver via feedback from the front wheels. In general, the linkage boost systems (where the steering wheel actuates a hydraulic valve) offer little. Manual systems obviously offer the most road feel to the driver. The information that the driver receives via his tactile sense (from the steering wheel) may concern some unusual abnormality, such as a tire going soft (pull in that direction), which has a direct bearing on continued safe operation of the vehicle. Such effects can be (and often are) masked by power steering systems that have little or no road feel.
3. Power brakes.-Power brakes are also gaining in popularity; from 1960 to 1969 the percentage of U.S.-made cars equipped with power brakes increased from about 22 to about 54 percent. The driver receives feedback information pertinent to his braking rate kinesthetically and by
visual perception of external cues. The minimizing of tactile information as to the amount of force applied to the brake pedal, which is a feature of power brakes, is thus not important. However, power brakes mask feedback information about deteriorating brakes.
4. Secondary power devices.-Many vehicles incorporate other power-operated devices, most of which have nothing to do with the primary driving task. These include power seats, power antennas, automatic radio tuning, power windows, automatic door locks, and automatic headlight dimmer. They do contribute to the comfort and convenience of the driver and, therefore, may enhance his information reception and processing abilities. Malfunctioning of these devices, however, may result in driver discomfort, and, hence, reduced attention to the primary driving task. Furthermore, malfunctioning of a device, such as the automatic headlight dimmer, may force the driver to assume the task manually-a task to which he is not accustomed.
5. Summary.-Automatic and power equipment make the driving task simpler and easier. However, these devices may mask feedback information to the driver relative to the vehicle's operating condition. In addition, under unusual conditions that demand prompt action by the driver, these devices may mask the "message." Consequently, the driver may take no action, or may over-react, to the potential detriment of vehicle, driver, and passengers.

Suspension and Seats.-The degree to which the driver kinesthetically perceives what is happening to his vehicle relative to the road depends, to a considerable extent, on the suspension components (shock absorbers, springs, torsion bars, air/oil-type suspensions) and seats. There has been a trend to isolate the driver from the road with softer springing and softer, more luxurious seats. Both of these tend to damp out evidence of road irregularity, changes in surface, etc. They may also mask the onset or existence of an abnormal or potentially dangerous condition. Thus, although such improvements may make the driving task more relaxing and comfortable, they may also eliminate a potential source of information.

Chassis, Body, and Interior.-Similar observations can be made with reference to interior appointments, which have become more luxurious. Interiors are padded and insulated acoustically to enchance the aura of quiet comfort and luxury. Although some of these features contribute to greater enjoyment of automobile ownership and use, some problem areas are introduced that affect the driver's ability to perform his function.

For example, soundproofing (in conjunction with air conditioning which allows for driving with closed windows)* isolates the driver acoustically from the exterior environment much as soft suspension and seat padding isolate him from the road. Simultaneously, considerable effort has been expended by the automobile industry to quiet engine noise. This kind of progress carries with it the possibility of driver drowsiness, resulting from the lack of any significant aural or tactile sensations.

Additional features worth considering are aspects of

[^2]vehicle design that are purely esthetic rather than functional. For example, certain roof designs result in large blind spots in the driver's rear view. Inasmuch as one of the driver's information needs is that pertaining to adjoining lane traffic, such blind spots seriously impede his view, and, for short, although significant, periods of time, deprive him of this information.

Very wide, wraparound windshields produce distortion and reflection, which can provide false cues and cause the driver to react to situations that do not exist.

Sun visors shield a driver's eyes when he is driving directly into the sun when it is near the horizon; however, they also obscure the top portion (nearly a third) of the driver's total forward field of view and may cause him to miss an overhead sign or signal. Tinted glass may visually isolate the driver somewhat from the environment, especially at night. The position and geometry of the rear-view mirror, the location and width of front corner posts, the rear-window size, and the normal position of passengers in the rear seat also limit the driver's field of view.

Placement of Controls.-Whereas there is standardization in the placement of primary controls (steering wheel, accelerator, and brake pedal), the placement of secondary controls varies in U.S. and imported automobiles.

Secondary controls, including heater/defroster controls, blower switch, and radio, are placed "logically" and "conveniently" in different arrangements and locations. Furthermore, there is a great variety in types of operation. The same control, depending on the manufacturer, may be a toggle switch, a push-pull knob, a rotating knob, or a bar switch.

Because most drivers on the highway drive their own cars, the various control types and locations may not seem to present a problem. However, in the familiarizing process, this aspect can cause problems. In his search for a particular control, a driver may be distracted from the driving task long enough for a potentially dangerous situation to develop. Even the primary controls, by being positioned at different angles from those to which the driver is accustomed, may cause tension, discomfort, and, hence, distraction.

The horn is used relatively infrequently, and normally only in emergency situations; therefore, it is important that the driver be able to use it instantly when necessary. On all U.S. vehicles, the horn actuation mechanism is integral with the steering wheel, but there the uniformity ends. There are horn rings, horn bars, horn buttons, and squeezable wheel rims. In some vehicles it is necessary to remove a hand from the steering wheel to actuate the horn mechanism. It is suggested that the location of the horn mechanism, its type, and its actuation be standardized; furthermore, it should be positioned so that it can be operated without removing a hand from the steering wheel.

Interior Displays and Indicators.-Speedometers usually are placed directly ahead of the driver in clear view; however, the ease with which their indications can be interpreted varies widely. Indications vary from horizontal and ribbon to horizontal and pointer (highly nonlinear),
vertical and ribbon, and circular and pointer (usually about $270^{\circ}$ ). Except for circular speedometers, most can be read only to the nearest multiple of 5 mph , thus requiring that the driver make a qualitative interpretation of his speed detined to a $\zeta$-mph interval. Furthermore, depending on the distance between the markings and the indicating element (needle or varicolored ribbon), this judgment will be affected by parallax. This will affect his speed tracking performance; if he attempts to keep the needle in some particular position relative to a marking, changing his position in the seat or moving his head will result in the indicator being in the same position at a slightly different speed.

In conjunction with the speedometer, there is usually an odometer, which totals the miles traveled by the vehicle. The odometer is not a primary instrument, although it can be useful in helping the driver to perform some of the direction-finding portions of the driving task. Some automobiles also have a trip odometer that enables the driver to reset it at zero.

Another instrument that is used almost universally is the gasoline gauge. Gasoline gauges are usually inaccurate and highly nonlinear. Most indicate Empty while there is still a gallon or two remaining in the tank, and reliance on this margin has left many motorists stranded.

There are a number of variables that indicate the operating condition of the vehicle. The most important of these are oil pressure, engine temperature, and state of the electrical system. Whereas gauges have been, and still are, used to measure these variables, most passenger cars manufactured in the U.S. now use "idiot lights" to indicate an abnormal condition. In some cases when gauges are used, rather than indicating quantitative values, the dial may display varicolored ranges; for example, green for normal, amber for marginal, red for abnormal. There is no standardization as to the placement of gauges or indicator lights.

Lights are cheaper and simpler for the manufacturer to supply. This disadvantage lies in the fact that no indication of a gradually worsening condition is given, such as is available with either type of gauge. It is argued by the automobile industry that the average motorist is not interested in actual values, but only wants to know whether it is "right" (no light) or "wrong." For this reason, it is suggested that a meter properly calibrated, on a multicolored background indicating "normal" and "abnormal" operating ranges, supply all motorists with the type of information that they want or can assimilate and act on.

Another class of indicators consists of those that indicate the instantaneous state of one of the vehicle controls. These include gear indicators, high-beam indicators, emergency brake warning lights, and turn-signal indicators. All remarks previously made as to the need for standardization of location and color apply equally here. This class shows promise of being expanded to furnish the driver with additional information concerning his vehicle's operation, especially of components that cannot be checked by direct observation. The vehicle's external lighting system, especially tail and brake lights, is a prime example.

Intervehicular Communication.-Intervehicular communication deals with the ability of the driver-vehicle unit
to receive and transmit information from or to other drivers in the traffic system. Basically, there are five methods by which this is accomplished:

1. Perception of the vehicle.
2. Vehicle lighting system.
3. Brake lights.
4. Horn.
5. Turn signals.

Perception of Other Vehicles.-Most of the information that a driver obtains about the position, direction, velocity, and acceleration of other units in the traffic stream is obtained by direct perception. Although this perception is mostly visual, it also contains auditory elements (car noises) and even some kinesthetic elements (vibrations induced by heavy trucks). The information may be obtained by a single glance at the entire vehicle or successive glances to evaluate dynamic aspects; it may be the result of an inference based on the position of the vehicle's wheels or visible actions of the other driver.

The more visible a vehicle is, the more easily this information will be received. Fire equipment, construction vehicles, and school buses use high-visibility colors (red, orange, and yellow, respectively) for this reason. Colors for passenger cars are determined, almost exclusively, by personal taste. Although there appears to be a trend toward lighter colors, these are not necessarily more visible. Second only to color as elements to enhance visibility are shape and size. Although automobile size has been holding steady for some time, there is a long-term trend toward lower heights, which adversely affects visibility.

Vehicle Lighting System.-In darkness and in heavy fog, perception of vehicles is replaced by perception of the vehicle's lights. A car's headlights, or parking lights, and its tail lights together indicate the position of the vehicle to other drivers ahead and behind. Furthermore, backup lights, now mandatory for all new vehicles, are a source of information as to the intentions of a driver. Starting with the 1968 model cars, side running lights will supplement this information.

However, no lighting system, short of floodlighting, will enable a driver to make the fine inferences possible from daylight observations. Therefore, the availability of information will always be less at night. In view of this, and in view of the fact that a vehicle's illuminating system is prone to electrical and mechanical failure, the use of reflecting devices at the car's extremities should be mandatory.

Brake Lights.-Brake lights indicate to following motorists that pressure is being applied to the brake pedal and that there will be a consequent deceleration of the lead car. As an information source, however, it suffers from several disadvantages.

One disadvantage is that the brake light is a binary device; that is, it can indicate only on or off. Information cannot be obtained on the rate of braking, let alone on the consequent rate of deceleration. Also, braking is not the only means of decelerating a vehicle. Deceleration also results from removing or reducing pressure on the accelera-
tor. Furthermore, brake lights do not include any kind of fail-safe indication. Therefore, if too great reliance is placed in them by following drivers, failure can result in catastrophic consequences.

A second class of deficiencies is inherent in current design of brake lights. They are almost always physically combined with the tail lights, with both lights the same color (red) and differing only in intensity. Especially at dusk and dawn, when tail lights may or may not be on, it is sometimes difficult to perceive the appearance of the brake lights. Keeping car lights on during daylight hours, an alleged safety device apparently becoming fashionable, complicates the problem because certain low-intensity brake lights are difficult to distinguish from tail lights under high ambient light conditions. No standards exist for brake-light brightness, or of brightness differential between brake lights and tail lights. Consequently, cars now have brake lights ranging from barely perceptible to blindingly bright. There is also no standard for size, shape, or number of brake lights. Every possible configuration, usually dictated by styling considerations, can be found. Finally, brake lights usually are mounted so low that, in addition to being prone to mud and ice packing, they may easily be invisible to a following motorist under extremely reduced headway conditions, such as in urban traffic or under expressway stop and go conditions. Most emergency vehicles now have high-mounted brake lights to overcome this difficulty.

It is therefore recommended that brake lights be moved to a high position, be physically separated from tail lights, and be clearly identified by standard size, shape, and brightness. Variable brightness, as a function of ambient lighting, might also be advantageous. It is further recommended that brake lights be supplemented by a "nonacceleration" indicator that would indicate the absence of accelerator pedal pressure. The possibility of a "panic stop" (maximum possible brake application) indicator might also be investigated.

Horn.-The location of the horn control is discussed elsewhere. Functionally, the horn emits an auditory signal with a meaning of general warning. On rural roads, and especially among commercial drivers, the horn signal is also used in the sense of "I am about to pass you," or "Is it safe to pass?" The effectiveness of the horn is somewhat reduced by the trend to more insulated car interiors and the increasing use of air conditioning, with the net result of increasing the acoustical isolation of the driver. The horn, as an effective warning and signaling device, also suffers from a lack of standardization as to volume, fre-1 quency, and modulation of the sound emitted. Such standardization, as well as the elimination of novelty devices such as bells and whistles to replace the horn, is recommended.

Other aural signaling devices fall into two classes: (1) the siren or bell used on emergency vehicles, and (2) the bell or whistle reserved for railroad grade crossings. In both cases, the information transmitted is of extreme importance, with reception failure carrying a high possibility of catastrophic results. It is therefore essential that this type of signal be restricted only to its intended purpose
and not be used indiscriminantly. In this connection, the use of sirens, bells, and horns as attention-getting devices on radio commercials, which are likely to be heard from car radios, represents a source of spurious information and is, therefore, potentially dangerous.

Turn Signals.-Flashing lights of turn signals (amber in front, red in rear), when actuated by the driver, inform nearby drivers of an intended change in lateral position, either a turn or a lane change. They are also used as an informal "safe to pass" signal, in response to the horn interrogation already mentioned. With the addition of a relay, now required equipment on new cars, both sets of turn signals can be made to flash simultaneously, thus serving as a general warning, and usually indicating a stationary vehicle.

The turn signal, being entirely volitional and requiring conscious actuation by the driver, suffers from the lack of uniform and predictable use. Furthermore, because the automatic cancelling devices are prone to mechanical failure and are not reliable for less than $90^{\circ}$ turns, and because it is relatively easy to actuate most turn signals inadvertently, the occurrence of spurious signals is prevalent. Additionally, turn signals share many of the shortcomings attributable to location, design, and lack of standardization already discussed for brake lights.

## Highway

For the purpose of this study, the highway * is considered from three separate aspects, realizing that there is considerable overlap and tradeoff and that the influence of no single element can be clearly assigned to any single aspect.

1. The highway generates a need for information. One of the most important parts of the driving task is the maintenance of a steady-state relationship between the vehicle and the fixed elements of the highway and the implementation of conscious and deliberate changes in this relationship. This task depends on information on the structural, alignment, and cross-sectional elements of the highway, both immediate and in the near future.
2. The highway gives information. A great proportion of the necessary information can be satisfied, directly or inferentially, by perceiving the highway. The analysis of the manner in which the various individual highway elements combine to enhance or to hinder this perception is essential to an understanding of information needs and their satisfaction.
3. The highway affects information. Beyond the roles of the highway described in items 1 and 2, the highway affects-that is, it colors or modulates-the transmission and reception of all information necessary for the driving task.

It is worth noting that these aspects correspond to three of five parts of a communication system as defined by Shannon and Weaver (19). In the order just listed, these

[^3]aspects correspond, respectively, to information source, transmitter, and channel. The fourth and fifth part are, respectively, the receiver (message decoder) and the destination (message user). However, for most of the information sources and transmission techniques discussed in this report,* the receiver and the destination are united in the driver. It can thus be seen that the highway in its various aspects influences nearly all facets of information.

Highway as an Information-Need Generator.-The driver requires information concerning all approaching changes in structural, cross-sectional, and alignment elements. Obviously, the greater the frequency of such changes, the greater the frequency of information need. Equally, the more severe the individual changes, the more urgent the need for information. Finally, if changes in more than one element coincide (e.g., a lane drop in the middle of a curve), the information to be transmitted and received will be more complex.

Although it is not stated in these terms (the emphasis is usually more on easing the driving task than on minimizing information needs), the principle of minimizing changes, in frequency as well as severity, is accepted by most highway engineers. This is especially true as applied to arterial highway, expressway, and freeway design as can be seen by examining the pertinent AASHO design policies $(21,22)$.

Alignment, both vertical and horizontal, number and width of available traffic lanes, shoulders and medians, and type of surface are not the only highway elements about which the driver needs information. Every highway intersects or interchanges with other highways, and with driveways or private access roads; therefore, information is required concerning the configuration of these interchanges and intersections.

The frequency and spacing of these intersections and interchanges, and of any other discontinuities in the basic roadway, are determined by considerations of economics and land use. Except for the major step of upgrading a highway (e.g., from partial to full control of access), no method is available to minimize the frequency of these discontinuities and, therefore, the frequency of the need for information about them.

The effects of highway element changes and the effects of highway discontinuities can, and do, coincide spatially. Changes in horizontal and vertical alignment and in highway cross section may occur within an interchange or intersection, or very close to one, so that the two types of information needed coincide, become additive, and increase the load on the driver. This is evidently one area where a critical look at preliminary alignment and design plans can be beneficial.

Information needs can be minimized by controlling the frequency and severity of changes in highway elements and attempting to standardize interchange and intersection design as far as possible. (In the case of grade-separated interchanges, this would mean a single ramp takeoff and a single ramp entrance located at the right side of the through lanes in a flat, tangent section.)

[^4]Highway as a Transmitter of Information.-Concerning visual information provided by the highway, Rockwell and Ernst (23) found that highway design features are the principal cues for lateral position control.

It must be remembered that the highway also transmits information on other channels. Prime among these is the kinesthetic channel where every perturbation in the roadway, whether natural or constructed for the main purpose of giving information, is received by the driver. This is also true of those cross-section elements that, by influencing the front wheels and, therefore, the steering geometry of the vehicle, tend to guide the vehicle in a certain path. Finally, information transmitted by the highway is received via the auditory channel as, for instance, the "singing" of some types of medians and open-grate bridge decks.

For a driver to receive information from a highway element, it must lie within his field of vision ( $8,9,13$ ) as attenuated or limited by prevailing atmospheric and lighting conditions and not be blocked from view by any intervening obstruction. Furthermore, for the information to be used, it must be understood by the driver.

The limits of the driver's field of view are determined by physiological considerations not subject to influence by the highway designer. He can, however, influence attenuating or limiting factors, as is the case with fixed highway illumination. Work on other attenuating factors, including fog abatement, is under way $(24,115)$.

When the decision on fixed highway lighting is made and an expected range of climatological attentuating factors is postulated, the visual field of the driver, as limited by vehicle design, is fixed. Any feature physically contained within the limits of this visual field can therefore be presumed to be seen by the driver and able to transmit information on the visual channel (unless the line of sight is blocked by an intervening object). In this connection, it is worth pointing out that the problem of signs blocked by moving trucks (see "Blockage of Signs by Trucks" of this Part I) exists equally in the case of the blockage of other highway elements.

Elements of the highway system whose direct perception by the motorist will help satisfy his information needs must be identified and every effort must be made to keep the line of sight open to them. Similarly, every effort must be made to eliminate from the line of sight elements that may be distracting, provide false information, or foster false inferences on the part of the motorist. The most obvious (and easiest to manipulate) tool in this respect is landscaping, including the selective clearing of existing vegetation.

One of the prime attributes of the "complete" highway (25) is safety. One of the methods available to achieve this is to keep sight distances open on curves and at intersections. This follows naturally because a driver can handle an expected situation better than one that surprises him. Future alignment, especially if changes in it require major control actions by the driver, and future changes in cross section, especially if they result in a net change in the number of available lanes, represent important information inputs to the driver. Changes in these features must be apparent to the driver and not hidden from sight. It must be realized that the driver also draws inferences
from visual inputs. Therefore, visible features that might lead to false inferences should be suppressed. If, for example, the alignment of a highway does not follow the natural topography of the terrain, every effort must be made to obscure the perception of the topography to minimize these false inferences.

All visible highway features give information to the motorist. This information can be useful only if it is correct and understood by the driver. For example, a driver looking downstream and encountering no obstructions to his vision can perceive the future cross section of the road. However, if there is no clear distinction between the road surface and the shoulder, his perception will be faulty and his conclusion concerning the number of available lanes will be erroneous. On the basis of past experience, he will tend to equate certain visual images with certain changes in cross section and alignment. If, for any reason, a given highway situation represents a conflict between this expectation and the actual conditions that will be encountered, every effort must be made to change the visual image.

Highway as a Modifier of Information.-The reception and use of all information received by the driver during a trip is affected by the highway in more general terms than the specific factors of information generating and transmitting previously discussed.

The driver's ability to receive and process information is a subjective variable, varying for individual drivers in accordance with momentary physiological and psychological conditions. These conditions are affected by the surroundings and the demands of the task being performed. It could be argued that the highway as a whole should be as restful and undemanding as possible to optimize the driver's ability to receive and process information. However, this is not the case. The concept of "highway hypnosis," as a potential danger, is finding ever-widening acceptance, as is the need for positive countermeasures. Rose (26) states, as one of the important functions of highway landscaping, ". . . the need to do everything possible to stop a driver from drifting into a state of drowsiness through boredom-a state of mind which can lead to danger." Head (27) stresses safety aspects in discussing the ability of natural and man-made features to "break the monotony" and give direction guidance. Smith and Fogo (28) point out the ability of the highway to lead the eye toward things that should be seen and away from things that should not.

It can thus be postulated that there is an optimum combination of the visual elements of the highway so that both boredom and visual overload are avoided. This same combination should minimize the creation of information needs and maximize their satisfaction. This total visual impact of the highway is receiving over-increasing attention, both within and without the highway engineering profession. Tunnard and Pushkarev (29) and Appleyard et al. (30) discuss this as part of the over-all design of the highway in the landscape.

Two difficulties are immediately apparent: (1) determining this optimum level quantitatively and evaluating the influence of individual factors, and (2) simulating and
evaluating these aspects prior to construction of new highways. Appleyard (30) developed a technique for evaluating the total visual impact of the highway; if it were modified slightly to emphasize the alignment and crosssectional elements discussed previously, it should prove extremely useful. As far as the evaluation of proposed highways or proposed changes in existing highways, the total impact will be much more difficult to obtain. The most feasible method appears to be an expansion of the model technique discussed by Berry and McCabe (31). A promising approach, in the development stage at UCLA, is the use of a computer to simulate the visual perspective of the driver using highway design data as the input.* A similar approach is described by Weisberg (32).***

Environment.-There are information sources and factors influencing the transmission and receipt of information that cannot be properly assigned to either of the broad classes of vehicle or highway. For ease of discussion, these are categorized as environment. Environment consists of several distinct parts: (1) landscape, (2) nonvisual, and (3) climatological.

The physical components of the landscape falling outside the limits of the highway range from 17 percent of the driver's field of view at 60 mph on a six-lane freeway to 82 percent at 25 mph on a two-lane road (29). Recognition of this fact has led to the gradual abandonment of the old idea that a highway designer's responsibility ended at the right-of-way line. The "Landscaping" chapter of one handbook (33) states: "It is evident that highway planning in this sense should extend beyond the limits of the pavement and beyond the public right-of-way."

The importance to the driver of structuring the entire visual environment received official recognition with the passage of the Highway Beautification Act of 1965 (34). Among the stated purposes of this Act is ". . . to promote the safety . . . of public travel." Whether any correlation between roadside advertising, one of the principal targets of the Highway Beautification Act, and accidents actually exists is not a settled question. Wagner and Marder (35) collected a number of studies that tend to indicate that this correlation, if it exists at all, is not universal. Several of the principles and concepts derived as part of this study, and discussed in later chapters, give an indication of why this correlation may change from one location to another, and why, as one of the collected studies indicates, advertising may have beneficial effects under certain conditions.

Godschalk (36), using concepts developed by Hall (37), stresses "the importance of a clear structure of spatial organization for decision making," and states, "[P]erhaps both beauty and safety are involved in a satisfactory system of information about environmental order." Sears (38), after stating that "the responsibilities of highway location and design extend to whatever can be seen," discusses the problems inherent in evaluating and achieving these objectives.

The total external visual input to the driver which, in addition to highway elements, discussed previously, in-

[^5]cludes natural and planted vegetation, topographical features, and all man-made objects, competes with or complements the visually received information. The deserts of Nevada, the cornfields of Iowa, and the scenic coast of Maine must be evaluated in these terms, as must the subdivisions of Long Island or Pittsburgh's Golden Triangle.

Summarizing the preceding discussion, it can be seen that the concept of total design is receiving ever-widening acceptance. The importance of fitting formally designed visual information sources into this total design, and realizing the influences of one or the other, appears to be an obvious corollary.

Information is not always received visually; nonvisual factors also influence the ease with which information is received and processed. The nonvisual components of the environment, as defined, represent the second distinct portion of environment to be discussed. Subjective human and population variables are discussed at length elsewhere in this report.

The driver, engaged in the driving task, has been described and postulated as being in a vehicle and on a highway. However, he is not always alone in that vehicle; about one-half of the time he will be accompanied by one or more passengers.* The presence of these passengers points out that the driver is receiving information not germane to the driving task of the moment. By definition, this information is noise,** although the driver may not realize this until after the information has been processed. Radio programs, other audio reception, and every sensory input other than visual (which may provide informationnoise or tend to mask the receipt of necessary information on a given channel) can be included in the category of environment.

Although the highway engineer may have actual or, through legislation, potential control of the driver's visual environment, he has little, if any, actual or potential control of the nonvisual environment. For this reason, it is even more important that the presence of these possible distractions be realized to ensure that needed information is presented in a manner so that it can "get through" to the ultimate user.

A third aspect of environment consists of climatological and quasi-climatological factors, including precipitation, wind, smog, and industrial emissions. These include factors that affect driving directly (such as wind), factors that affect driving indirectly by changing the relationship of the vehicle to the road surface (such as ice), and factors that affect the driver's ability to receive and/or process information (such as extreme cold or heat or carbon monoxide levels).

All of these factors must be considered in the design of an information system, although direct control, with minor exceptions, is not possible.

[^6]
## FIXED HIGHWAY SIGNING

## The Role of Signs

The following statements can be made concerning the extent to which visual communications can be used successfully to transmit information to the highway user:

1. Visual communications have been and are presently the primary means of transmitting information to the driver.
2. Visual communications have, for the most part, successfully satisfied the majority of information needs of the driver at the situational and macroperformance levels. This does not imply that improvements in visual communications techniques cannot be effected or that, in certain instances, nonvisual communications techniques could not prove successful. What it does mean is that there are no overriding reasons to abandon the present visually oriented communication system.
3. The extent to which visual communications can be used successfully is difficult to specify, being a function of many variables such as level of performance, complexity of the situation, prevailing climatological factors, and geometric design. However, the extent to which visual communications can be used successfully, given an optimization of all other factors (reception limitations, transmission factors, highway elements, etc.), probably encompasses nearly all possible driving situations.
4. Visual communications will and should continue as the primary means of transmitting information in the foreseeable future.
5. Signs are the main technique of visual communication for macroperformance information and for certain microperformance and situational performance information. There are several cogent reasons for retaining and maximizing the use of the sign as the primary aided visual display technique.
a. Expectancy: Drivers expect to receive information from signs, yielding an acceptance and readiness on their part to respond to messages displayed on signs.
b. Investment: Because sign panels and supports presently exist, costs of any changeover to a new information system will be minimized.
c. Changeover and Coexistence: Because a system of signs presently exists, a gradual changeover to a new system will not be difficult. Furthermore, a new system can easily coexist with the present system during the changeover period.
d. Implementation: Personnel, organizations, technology, and equipment necessary to implement any sign system already exist.

## Signs Considered as Communication Systems

A communication system, according to the theoretical considerations of the subject (19) consists of the following parts:

1. Information source.
2. Transmitter.
3. Channel.
4. Receiver.
5. Destination.

The presentation of information on the visual channel can be considered such a system. In this case, the driver combines the functions of receiver and destination. The channel is the beam of light impinging on the retina. The most common method of displaying information on the visual channel is through the means of fixed-message signs. The sign then combines the functions of information source and transmitter. In this section, the attributes of signs are considered from these aspects. Because noise, an attribute of the channel, may also occur at either terminal, it also is considered.

For the sign to fulfill its function, there must be a message. Although not necessitated by the theoretical analysis, it is assumed that this message contains information and that this information will satisfy an information need of the highway user. This need must have an identifiable place on the primacy scale. For the information need to be satisfied, the information message must be processed by the highway user. It must therefore be received and understood.
Receipt of a message depends on its being transmitted with the receiver tuned to the necessary channel. The image of the verbal and symbolic coding elements forming the message must therefore be capable of being discriminated, and the driver must also be able to detect the sign. For the message to be understood, the driver must know the verbal and symbolic code used, and the message must relate to his store of a priori knowledge. Finally, the message, when received and understood, must be the basis of a decision that can be implemented.

Because the driver is operating under some degree of time and task sharing constraints, detection, legibility and comprehension, by themselves, are insufficient. Each of these attributes, singly or in combination, must be optimized. The attributes of the sign, which contribute to the optimization of legibility and detectability, are the physical components of sign design; the attributes that contribute to the optimization of comprehension are inherent in the message. Comprehension is a consequence of the sign's function as an information source; legibility and detectability are consequences of its function as a transmitter of information. The degree of noise present at the transmitter, channel, or receiver affects all three elements.

## Signs as Information Sources

The message, when received, is processed by the driver and forms the basis of decisions made by him. The correctness of these decisions, and the consequent successful completion of the driving task, depends on quick and clear understanding of the message. Proper consideration of the following factors will tend to optimize quick and clear understanding.

1. Comprehension: The message should minimize all potential sources of misinterpretation and ambiguity. The message should not depend on a high order of logical deduction for its comprehension. The amount of a priori knowledge necessary for comprehension and use of the
information contained in the message must logically be expected to be possessed by most drivers. The message must be analyzed for its potential in generating negative reasoning.
2. Emphasis: The most important information (needed by most drivers, requiring most immediate decision or whose nonreceipt could have the most adverse effects) should be emphasized by size, location, letter type, color, underlining, or other means.
3. Rejectability: Without compromising other principal factors, the design of the sign should be such that the information can be quickly rejected by drivers not needing it.
4. Expectancy: Legend and location should conform to the driver's expectation based on pretrip planning, a priori information, previously seen signs, and subjective evaluation of the driving situation.
5. Uniformity: Furnish similar types of information in a similar manner in similar decision situation. Conversely, indicate dissimilar, unusual, or unique situations by furnishing appropriate information in a manner that will indicate that an unusual driving maneuver may be required.
6. Sign Consistency: Keep the same types of information in the same general location on sign panels. Keep the same information in the same size and series insofar as possible.

These six items refer to all signs, whether used individually or in combination. Additional factors apply when a series of interrelated signs (such as signing for a complex interchange) is considered and where the understanding of a particular sign depends on the receipt and understanding of the information contained on other signs of the same series. These factors are:
7. Repetition: Information should be repeated sufficiently often so as to minimize the possibility of a driver forgetting between signs. Also, drivers who have missed one sign (due to noise or lack of vigilance) should be given a second chance.
8. Legend Consistency: The same information (e.g., route number, name, destination) should be carried on all signs until the need no longer exists. Incremental information (distance to exit) should always be consistent in arrangement and units of measurement.
9. Exclusiveness: New information should be introduced in a logical manner. No new information should be furnished after initiation of a necessary driving maneuver. No information should be given that does not affect the choice among alternatives in a given decision situation.

For the sign to comply with the last requirement listed for processing of the information (act as a basis for an implementable decision), two additional factors must be considered:
10. Alternatives: All alternatives should be clearly identified, and no unlabeled alternatives should be provided.
11. Beginning: The introduction of new information should be made sufficiently in advance of need to avoid hurried (or panic) responses.

## Signs as Transmitters of Information

## Detectability

The visual channel is characterized by its selective nature; a driver must detect a sign before he can begin to perceive the message it contains. This is an extremely critical factor in low-signal areas (e.g., rural freeways) where a driver may miss a sign due to low vigilance on his part or due to low detectability on the part of the sign. It is also critical in high-signal areas (e.g., urban arterials) where extraneous visual stimuli are competing for his attention, where competing information requires time-sharing, and where quick rejection is necessary for rapid load-shedding.

An important factor in detectability is contrast ratio, which is the relation of the brightness of the sign panel to the brightness of the surroundings. The greater the contrast, the greater the target value (all other things being equal). The designer is faced with two situations that are at variance with each other: (1) when the ambient brightness is low (as in nighttime driving), and (2) when the ambient brightness is high (as in daylight driving).

For nighttime driving, the designer can assume low ambient illuminations (in the range of from 0.4 millilambert to almost zero) and can therefore enhance target value by providing a high sign panel luminance. Because the critical factor is "background/surroundings contrast," the required luminance of the sign panel depending on ambient luminance may thus be only 1 millilambert, or even less. Thus, any external lighting, such as car headlights, may suffice to provide an acceptable target value. Target value at night is further enhanced by the fact that the eye is partially dark adapted and is therefore sensitized to low luminance levels. A sign may thus be detected even prior to a car's headlights actually illuminating it. Another, less critical factor in nighttime detectability is sign size. A larger sign subtends a larger visual angle and, especially if self-illuminated, can be detected as a point source at greater distances. Therefore, for maximum target value at night, the sign should have a bright background because this will provide maximum contrast with the dark ambient luminance.

However, the same sign that serves for night use must also function during the day, and here the situation is reversed. Target value is more important in daylight because there are more competing visual stimuli. Extraneous background stimuli, such as scenery, are perceptable under daylight conditions and not at night. The same principle applies during the day-that is, the panel surroundings contrast must be sufficient for detectability. The ambient luminance during the day is necessarily higher than that of the sign panel. It is therefore harder to obtain an acceptable contrast ratio with a bright sign panel, and maximum contrast and target value are more likely with dark sign panels.

Tradeoffs are therefore required to optimize simultaneously both daytime and nighttime target value of the same sign. One method to accomplish this is through the use of reflectorized background material that will appear dark during the day and bright at night. Another is the provision of self-illumination of the sign at night. The effect
of brightness, and of sign position, for simulated night and day conditions on first visibility of signs has been studied by Forbes et al. (116).

Brightness is one of the principal mechanisms for color discrimination; thus, a dull, nonilluminated sign may have its ability to transmit color impaired. Another is the color difference between the sign panel and the surroundings. This has been studied quantitatively by Odescalchi (117). Hanson and Woltman (118) have reported on the statistical distribution of background color.

## Legibility

Legibility represents the ability of a sign to transmit a group of symbols in such a manner that the individual symbols can be discerned. It does not imply understanding and comprehension, although the discrimination must be sufficiently fine to permit understanding and comprehension if the other prerequisites, discussed in the following are met.

The legibility of a sign message, for the driver, is a function of his visual acuity. The sign must present the message in such a manner that its component symbols can be recognized by the design driver at a specified distance. For a given driver visual acuity, the following elements can be manipulated to obtain optimum results:

1. Contrast: One of the principal mechanisms is the maintenance of high contrast ratio between the figure and the background.
2. Brightness: Visual acuity is optimum in a range of brightness from 10 to 30 millilamberts (13).
3. Letter Height: As the distance between the target and the observer increases, the visual angle subtended by the target decreases. When the visual angle falls below 5 min of arc (with 1 min critical detail) visual acuity, by definition, must exceed the "normal" $20 / 20$ to retain legibility. Increasing letter height, thereby subtending a larger visual angle, is the most obvious method of designing for a given visual acuity.
4. Message Ratio: The ratio of message size to sign area influences legibility. The smaller the ratio, the better the legibility. Data on this point are quoted by Hulbert (14).

Few, if any, individual areas in the field of highway communications have received as much research effort as has sign legibility. The research has been devoted to isolating and evaluating the effect of individual factors both on pure legibility, as defined previously, and on the combination of legibility and understanding. This research has resulted in a considerable body of data aimed at optimizing the design of individual coding elements (letters, numbers, and symbols), and their relative arrangement so as to increase discrimination and recognition. Forbes (42, 119), as part of a major study, has produced a review of previous studies in the field and an annotated bibliography.

Some specific examples of the areas covered include Christie and Rutley's (120) study of the relative effectiveness of upper and lower case and serif and sans serif letters. Kneebone (121) has studied the effect of letter height and series, whereas Case et al. (122) investigated
the effect of spacing. In the areas of nonverbal coding, Kelly (123) developed a color alphabet, whereas Brainerd et al. (124) have done work on symbology.

## Noise

Noise is defined as "any disturbance or interference apart from the wanted signal" (39). It thus includes two distinct aspects: (1) interference with the wanted signal, and (2) disturbances in the guise of unwanted signals that compete with the wanted signals. The selective nature of the visual channel and the consequent necessity of a volitional selection of the wanted signal from among all available signals is discussed elsewhere. Therefore, this section concentrates on interference with the wanted signal. In line with this definition, noise is considered to include those factors commonly described as attenuation.

The transmitter, channel, and receiver can all add noise to the transmission of messages. The concept of noise includes all factors that make a message more difficult to be seen and read. At the transmitter, dirt, age, physical degradation, vandalism, or accidental damage may reduce the brightness of the message elements or the contrast ratios between message and background (affecting legibility) or between background and surroundings (affecting detectability). Detectability is also affected by seasonal changes in surroundings.

Climatological factors play a large role as generators of noise. Snow and sleet may cake on the signal panel to the point where the message becomes completely illegible. More serious, because it is more prevalent, is dew, which under the right atmospheric conditions may also obscure the sign message completely. Because this phenomenon occurs usually at night, when both brightness and contrast ratio are most critical, an effort should be made to find means of abatement. One study (125) found some dew formation on sign panels at a test site in Minnesota on 37 percent of all nights observed during a 16 -month period and persisting for a total of 10 percent of all observed nighttime hours.

A sign message is legible due to the effect of light reflected by it to the eye of the observer. However, under certain conditions the entire sign, message and background, can reflect so much light as to eliminate any distinction between the message and the panel. This phenomenon, which occurs when the sign is normal to the axis of the impinging light beam, is called specular reflection. It has been studied and quantified by Gregsten (126), among others.

Under ideal conditions the channel (the connecting link between the transmitter and the receiver) will transmit the message subject only to the inverse square law and the laws of optics. Ideal conditions may be approached but are never achieved. Suspended moisture and some air movement are always present. Suspended moisture, in the form of fog, is one of the principal generators of noise on the visual channel. Again, the problem is especially acute at night because fog has the property of scattering light, thus degrading the headlight beam before it reaches the sign. This phenomenon has been studied by Pritchard and Blackwell (127), who derived some quantitative data.

All precipitation generates noise both by scattering light and by physical blocking of the line of sight. Smoke, haze, smog, and other industrial emissions may have an effect similar to fog, although usually of lesser severity.

The visual signal, before reaching the driver's eyes, must pass through the windshield and may pass through eyeglass lenses. Dirt present on these four possible glass surfaces will degrade the signal, as will the transmission losses due to passage through a solid medium. Even clear glass produces a definite loss in transmission. This loss is compounded by any tinting or other treatment of the glass. Haber (128) has studied the effect of tinted automobile windshields and has found a transmission loss ranging from 9 to 15 percent. The same study has also investigated the effect of wearing sunglasses at night and found a loss of 25 percent for one commercially available brand. A study of tinted contact lenses by Richards (129) found the transmittance of colored contact lenses to be as low as 71 percent, and quoted figures that indicate that transmittance of less than 85 percent, when added to the transmission losses of even a clear and clean windshield, can be considered dangerous.

Interference with the wanted signal may also be introduced due to distortion caused by curved windshields. A similar effect may occur if the line of sight passes near the edge of eyeglass lenses, especially those incorporating a high degree of correction. Veiling glare, caused by reflections on the windshield or by the presence of light sources in or near the line of sight, is another major source of visual noise.

Although not strictly defined as noise, even with the broad definition used in this section, physical obstructions to the line of sight, especially if caused by nonpermanent parts of the highway system, should be mentioned in this connection. These include vegetation (especially overhanging foliage), and temporary signs. The effect of blockage of the line of sight by other components of the traffic stream is analyzed and discussed in Chapter Three. The effect of the vehicle's corner posts, rear-view mirror, sun visors, other opaque projections, and eyeglass frames are other elements that should be considered.

Noise at the receiving end involves the many physiological aspects of seeing, which are not considered here. Two factors that impair the ability of the eye to receive signals are, however, not only prevalent but also amenable to some degree of control. These are headlight glare and tearing due to noxious emissions.

This survey lists some of the sources that introduce noise throughout the communication process. Some of these are of a type where positive action may result in elimination of amelioration. Others are fixed, for a given location, and must, therefore, be considered as factors influencing the information system design process.

## Sign Position

The effects of the position of a sign pervade all functional aspects of the sign as an information system so that they must be considered separately. All the individual factors discussed under the previous heading are fully or partly
determined by the sign's transverse and longitudinal location. These attributes of the sign, however, are not the only factors influencing location.

## Transverse Location

Transverse location should be chosen to maximize detectability and legibility and minimize potential safety hazard. The sign should be in the normal field of vision of the driver during the design reading time. Information applying to specific lanes should be physically related to these lanes. The apparent transverse sign location, at the point of first perception, should emphasize and not distort the horizontal alignment of the road.

## Longitudinal Location

The longitudinal location of the sign should be such that the driving action that may be required as a result thereof can be accomplished in a safe and convenient manner under prevailing and worst-case traffic and roadway conditions. The longitudinal location should be correlated with the horizontal and vertical alignment of the highway. Insofar as possible, the location chosen should be at a point where information needs of higher primacy are at a minimum.

Transverse location is thus, basically, the result of a tradeoff between safety on one hand and legibility and detectability on the other. Longitudinal location is a function of the point at which the information transmitted by the sign is needed. The prime determinant for this is, in turn, the time required to read and understand the sign message. The original work on reading time was done by Mitchell and Forbes (130). Recent work in the British Road Research Laboratory, reported on by Moore and Christie (131) and by Odescalchi et al. (132), has yielded slightly different results. All experimenters agree that reading time is directly proportional to the number of familiar words or symbols on a sign $(N)$. There are some differences as to the exact constant of proportionality that leads to higher reading times for the British formulation, especially as values of $N$ become relatively large. Additionally, there are some theoretical considerations; decision complexity varies as $2^{N}$, which may lead to the conclusion that the relationship between $t$ and $N$ is not linear for large values of $N$. The need for additional research in this area is apparent from the fact that reading time is a prime determinant of sign position and, indirectly, of message composition.

## Signing Techniques

The preceding discussion has yielded a set of factors that should be maximized in order to optimize the signs functions as an information source and as a transmitter of information. To achieve these ends, the sign designer has a set of tools available, that he must apply to achieve this optimization, realizing that simultaneous full maximization of all factors is impossible and tradeoffs will be required. Table 1 gives the variables that determine the physical aspects of signs.

However, the designer does not work in a vacuum. His
freedom of action is limited by a series of imposed constraints. These constraints, given in Table 2, must be considered as fixed in the short run, although a change in

TABLE 1
VARIABLES IN SIGN DESIGN
$\left.\begin{array}{ll}\hline \text { variable } & \text { CHARACTERISTic }\end{array}, \begin{array}{l}\text { Rectangle, square, circle, diamond, shield, } \\ \text { etc. } \\ \text { Shape } \\ \text { Total area, maximum horizontal and verti- } \\ \text { cal dimensions }\end{array}\right\}$

TABLE 2
CONSTRAINTS LIMITING THE DESIGN OF SIGNS

| CONSTRAINT | CHARACTERISTIC |
| :--- | :--- |
| Legal | Are there any legislative enactments requir- <br> ing certain information to be displayed or <br> prohibiting certain other information from <br> being displayed? Do similar restrictions <br> apply to size, materials, etc.? <br> What is the design life of the sign? What are <br> construction and maintenance cost limita- <br> tions? What is the benefit/cost ratio re- <br> quired to justify improvements? What <br> values are to be assigned to injury reduc- <br> tion in making benefit/cost calculation? |
| Economic | Are certain message units socially or cul- <br> turally unacceptable? <br> How much right-of-way is available for the <br> placement of the sign? Are there compet- <br> ing demands for this space? What are the |
| limitations on the line of sight? |  |
| Spatial | What wind and snow loading has to be con- <br> sidered? What are soil conditions? <br> What adjustments have to be made for the <br> projected level of maintenance and en- <br> forcement? What is the definition of the <br> design driver? Are special driver groups |
| to be served? Are there any other admin- |  |

these constraints may be the only solution to a specific signing problem or may represent the best chance for future development of the sign as an information system.

## Investigations of Aspects of Signing

In the course of this project, three distinct aspects of signing received detailed attention:

1. Sign design for night legibility.
2. Blockage of signs by trucks.
3. Effect of lateral sign displacement.

The work done in each of these areas is described subsequently herein.

## TERMINOLOGY

Throughout this report a conscious and deliberate effort is made to avoid the unnecessary use of the jargons of psychology, human factors engineering, traffic engineering, automotive engineering, and other disciplines involved, insofar as possible within the limits of a technical report. Words are used in their normal everyday connotation. unless a specific, generally known technical meaning is obvious from the context. Any word use departing from this rule, as well as the use of any word, either borrowed or coined, used to describe concepts developed during this research is clearly defined on first appearance.

However, a thorough appreciation of the intended meaning of several words or expressions, used throughout the report, is basic to an understanding of the material presented. These terms are, therefore, defined in the following.

By driving task is meant the sum total of all activities taking place from the inception of a trip to its termination. The inception of a trip occurs when the decision to undertake a trip is made and a destination is chosen. The term "driving task" thus has a broader scope and time scale than the word "driving" and involves activities before and during the actual trip.

The terms driver, highway user, and vehicle operator are used interchangeably to denote the person in physical control of the vehicle and responsible for the decision-making and decision-implementation necessary to accomplish the driving task.

Information is defined here as consisting of everything that reduces uncertainty. Uncertainty implies that no unequivocal choice can be made between any number of possible alternate decisions in accordance with predetermined premises. In other words, as long as uncertainty exists the alternate decisions cannot be fully evaluated with respect to every single one of these premises. In order to make rational decisions the driver must reduce his uncertainty. The need to reduce uncertainty generates an information need that requires information for its satisfaction.

## ORGANIZATION OF REPORT

This report is a consolidated final report on NCHRP Project 3-12 and its continuation, NCHRP Project 3-12/1. The present report therefore supersedes the final report on Project 3-12, submitted by the researchers in November
1967. Substantial portions of this earlier report are incorporated in the present submission.
Following this Chapter One, "Introduction and Research Approach," Chapters Two and Three present findings of the report. Chapter Four is "Applications and Implica-
tions." Conclusions and suggested research appear in Chapter Five.

Supporting material appears in Appendices A through G.
Appendix H, meant to be used separatcly, is "Notes for
a Manual on Information System Review Procedures."

# FINDINGS—DRIVERS' INFORMATION NEEDS AND THEIR SATISFACTION 

## HIGHWAY USERS' INFORMATION NEEDS

The first phase of this study addressed itself to the question, "What information is needed by highway users for safe, convenient, efficient, and comfortable performance of the driving task?" The importance of providing drivers with the information required to perform the driving task effectively is pointed out by the quotation by Cumming (1) in Chapter One.

The increased perceptual demands placed on the driver by the highway environment of today have been described by Connolly (13). From the vast amount of signals presented to him, the driver must select those that contain relevant information. Also, he may not receive adequate information to perform the driving task efficiently. This may result in an inconvenience (such as failure to receive route information), or it may lead to a serious accident (such as failure to receive the information that the vehicle ahead is decelerating rapidly).

A systematic approach was used to determine the nature of the information needed by highway users. It provided a framework for conceptualizing the form and timing of information so that it can be used most effectively by drivers. Viewing the driver as an element of the highway system suggests a "human-engineering" or "man-machinesystems analysis" approach. This approach has been used primarily in the analysis and design of military systems and is considered by the Air Force to be an integral part of aerospace subsystem design (40). Its application to the study of driving has been suggested by Platt (41), Forbes et al. (42), Grime (43), and others.

## Task Analysis Procedure

In the empirical part of this study, the driving task was investigated through the use of a task analysis, which Seale (44) defines as:

> which defines systematically and in as much detail as possible at any given time, the stimulus inputs to the possertor, the response output of the operator, and the operator operational environment in which he works.

Various schemes have been used in the development of
task analysis formats, ranging from Honsberger et al. (45), whose method consisted of questioning operators in situ, to Kurke (46), who devised a system of diagramming the operator's task in terms of his decisions, actions, transmitted information, and previously stored information. Each scheme contains an analysis based on information inputs and operator decisions and actions.

Although the task analysis methodology is used extensively in military systems analysis, its use in driver-related research has been limited. A method similar to the task analysis methodology is the use of an "events recorder" developed by Greenshields (47), that records events in a driving trip, and that has been used by Platt $(48,49)$ to evaluate the effects of fatigue on driving performance. Others, such as Algea (50), and Briggs (51), have analyzed portions of the driving task. To date, the most detailed attempt to analyze the driving task as a whole has been Miller's (52). However, the purpose of Miller's paper was simply to illustrate the technique of task analysis using the familiar task of driving an automobile. Consequently, it had neither the breadth nor the attention to information inputs to satisfy the needs of this study.

Several task analysis formats were tested on short field trips. It was decided that the task analysis format that would best serve the objectives of the study would be a modification of a task analysis developed by Alexander (53) in a study to determine information needs and control actions of bomber pilots and other airborne personnel on a military attack mission.

The final format provided for recording the following:

1. Odometer reading.
2. Speedometer reading.
3. Traffic situation-includes number of lanes, lane of own car, degree of congestion, and speed of traffic.
4. Driver perception-what observations made by driver.
5. Driver cognition-evaluations, predications, and decisions made by driver.
6. Driver response-overt action taken by driver.
7. Vehicle response.
8. Type of feedback-visual, auditory, etc.
9. Distractions.

Two additional columns were added so that suggested informational aids and other comments could be included.

In the course of data collection and analysis, it was noted that the format did not adequately handle the task of route finding. A revised format was developed and additional data were collected.

Appendix A contains a detailed discussion of data collection techniques and analytic procedures.

## Description of Driving Task (Fig. 1)

The driver performs a number of interrelated subtasks, some of them simultaneously. In seeking an over-all concept of the driving task, the researchers gave attention to the interrelationships between the subtasks. It was noted that these subtasks could be ordered into a hierarchy that describes the organizational content of the driving task. The hierarchy itself is ordered according to time scale and level of cognitive activity. The subtasks differ in the time scale relevant to their analysis from fractions of a second for steering to minutes or hours for trip route finding. They also differ in the level of cognitive (mental) activity required of the driver. The cognitive activity required for steering is nonverbal, highly overlearned by experience, and might be performed by an animal capable of operating the controls. The task of route finding, on the other hand, requires thinking in terms of abstract symbols, language, and maps.

Tracking and speed control, which are continuous throughout the driving task, are involved in the performance of all subtasks higher in the hierarchy. Route finding and trip planning affect all subtasks lower in the hierarchy. In between are subtasks responding to road and traffic situations.

## Levels of Performance

Because the vehicle-control tasks low in the hierarchy are those observed in looking at the fine detail of the driving task, they are referred to as microperformance. The term macroperformance refers to the large behavioral units at the other end of the hierarchy. Because the remaining tasks in between consist mainly of responding to roadway and traffic situations, they are referred to as situational performance.

Microperformance.-At the micro level, there are two main subtasks: steering, and speed control.

Steering Control.-On a flat, straight road, the driver observes his lateral motion in relation to the road, and applies minute corrections to the steering wheel to maintain a "steady state" (54). The times required for such corrections are on the order of $1 / 2 \mathrm{sec}$. On horizontal curves, larger movements of the steering wheel are required to maintain lateral position, and several seconds may be required to complete traversing a curve.

The steering task depends on the driver's spatial orientation with respect to the roadway immediately and farther ahead of him. The work of Gordon (55) indicates that information on the position of road edges and lane divisions is of primary importance to the steering task.

Feedback information of the vehicle's response to steer-
ing-wheel movements is also necessary. The steering task has been characterized as "compensatory tracking" by Stephens and Michaels (56). Research on similar tracking tasks (12) is relevant to understanding steering. The behavior of the driver-vehicle-road system can be seen as analogous to a closed-loop servomechanical system. Such models have been proposed by Algea (50), Rashevsky (54), and Biggs (51). In addition to the kinesthetic feedback through his hands and arms, which tells how much the steering wheel is turned, the driver needs visual feedback of changes in the car's position and orientation with respect to the road.

He also receives "seat of the pants" feedback (kinesthetic and tactual) associated with centrifugal acceleration of the vehicle and lateral slope of the highway (such as superelevation). If centrifugal force is sufficiently high to be near the frictional resistance of the tires, tire noise may inform the driver of an impending skid.

Tracking performance is heavily overlearned so that it can, in most driving, be carried on without conscious attention. However, emergency situations may call for steering performance beyond the limits of the driver's experience, and he may lose control of his vehicle.

Speed Control.-Assuming automatic transmission, speed control requires the operation of two controls: the accelerator, and the brake. To maintain a steady speed on a flat road, the driver's task is comparable to steering on a straight road, requiring only minor adjustments. Changes in vertical alignment require larger changes in accelerator pressure, or even use of the brake pedal. Speed changes on vertical curves have been described by Lefeve (57). Although wind and engine noise and the speedometer provide speed cues, it appears that visual cues are of primary importance in speed control. Barch (58) found that drivers could make accurate speed judgments without a speedometer. Although consistent overestimates or underestimates were associated with the speed to which the driver was adapted, he failed to find the "velocitation" (underestimates of low speeds associated with long periods of driving at high speeds) that is commonly believed to exist. More recently, Denton (59) attempted to establish a subjective scale of speed. He found consistent errors in speed judgment associated with adaption, environment, day versus night, and physical state of the driver.

As with steering, speed control can be characterized by a servomechanical model, and the data of Todosiev et al. (60) are generally consistent with such a model. In addition to characterizing the maintenance of a constant speed, such models seem to characterize speed changes.

Each subtask affects the performance of subtasks lower in the hierarchy. Here, it is clear that speed control affects steering even in simple cases, as shown by Wohl (61). The speed of the vehicle on a given horizontal curve affects steering greatly, and braking to the point of skidding makes steering control almost impossible. Vehicle control requires integration of the two tasks, and anticipation of imminent vehicle control needs. In addition to maintaining the desired speed, the driver must observe changing conditions and respond so that he will arrive at every
point in the traffic situation at a "safe" speed-that is, a speed at which he can control his vehicle safely on the desired path.

The work of Olson and Wachsler (62) and of Olson (63) suggests that, for the experienced driver, differences of different passenger cars are not of overriding importance. Michaels and Cozan (64) and Gordon (55) indicate that the driver's visual perception of his position and motion with respect to the roadway are of primary importance to vehicle guidance. Engineers have developed highway designs that result in highways that do not present serious overdemands on vehicle control for most drivers and vehicles. However, further research on the process of vehicle control and differences in driver skills should make improvement possible in vehicle and consequent highway design.

Situational Performance.-Situational performance relates how the elements of road, traffic, and external environment, as well as other miscellaneous factors, may introduce large disturbances that cause the driver to apply complex control sequences to either return to a subjective steady state, or modify the subjective steady state.

The development used in discussing microperformance is continued in discussing situational performance. In the microperformance examples, the example of a single car on a rather featureless multilane highway with horizontal and vertical alignment changes is discussed. Although it is possible to approach such situations in rural areas, they are rarely experienced by most drivers. To the microperformance situation of a single car on such a road, the conditions imposed by other cars, speed limits, obstacles on the road, weather conditions, exits, and entrances can be seen to enter into the driving task.

Thus, situational performance can be characterized as being involved with the driver's objective of maintaining the most efficient and safe course, relative to factors in the environment which are generally beyond his control. As the term situational performance implies, the performance at this level is a function of the driver's perception of a situation and his ability to cope with the situation. Therefore, the driver must have a store of a priori knowledge on which to base his control actions, as well as an understanding of what the situation demands.

It is virtually impossible to describe every situation that a driver may encounter during a trip; however, it is possible to characterize some of the more common situations as illustrative of what a driver is called on to do in the situational level of the driving task.

Car Following.-Perhaps the least complex of the situational performance activities is that of car following, because the only deviation from the steady-state microperformance activities involves speed control modifications. In car following, the driver is constantly modifying his car's speed to maintain some safe gap between his car and the vehicle that he is following. Thus, in this situation, he is time-sharing his compensatory tracking activities with a more complex speed control activity. He now has to know how fast the lead car is traveling, what changes in its speed are occurring, how fast he is traveling, and the relative distance between his vehicle and the lead


Figure 1. Description of driving task.
vehicle, in addition to all other microperformance information needs.

Overtaking and Passing.-A second situational performance activity that commonly occurs is passing, which involves, in addition to speed control, modifications in the basic compensatory tracking activity. In passing, the driver is required to know many things in addition to all microperformance information such as how fast the lead car is traveling, how fast he is traveling, how fast other cars are traveling, and when he has an acceptable gap. He must, in terms of control actions, know how to maneuver his vehicle so as to use the adjacent lane gap most safely.

Other Situational Activities.-There are many other situational performance activities such as avoidance of pedestrians, and response to traffic signals, advisory signs, and railroad crossings. The important point, from an information standpoint, is that the driver must receive information about the situation so that:

1. He is aware of the occurrence of a situation.
2. He knows what the situation is.

Furthermore, he must possess the skills and a priori knowledge that will enable him to make the appropriate tracking and speed control responses. He should also have information that will indicate the adequacy of his responses.

At the situational performance level of driving behavior the driver is constantly time-sharing activity at this level with that at the microperformance level. Situational performance needs do not necessarily have to occur singularly. Two or more situational needs may occur simultaneously or in close enough time proximity to require simultaneous action. Moreover, the several actions may not necessarily be compatible, again pointing to the extreme importance of experience, skill, and a priori knowledge throughout the driving task.

The control skills required by the situational level of performance are about the same as those required by the microperformance level, except that more gross manipulation of the steering wheel, brake, and accelerator may be required, especially in an emergency. The differences between the two levels of performance are in the cognitive
components of the levels. Microperformance cognitive behavior is characterized by its overlearned, nonverbal nature, with major reliance on feedback from the road and vehicle as the main sources of information.

At the situational level of driving, the driver must scan his environment and obtain information from many sources (16) to maintain an appreciation of a dynamic situation. He must also rely on judgment, prediction, and estimation, as well as feedback, to maintain what Schlesinger and Safin (65) characterize as an "area of safe travel" relative to his car and the elements of the highway system. Although some cognitive behavior at the situational level is similar to that at the microperformance level, according to Algea (50) and Todesiev (60), most situational level performance requires a higher cognitive level.

The information needed by the driver at the situational level is that which enables the driver to maintain a complete appreciation of all events in the external environment that could possibly affect his safe travel. Thus, he needs information on the relationship of his vehicle to the road, other vehicles, and the environment.

Human factors studies on traffic information requirements have included studies on the ability of drivers to detect the speed and gap of other cars. Olson et al. (66) found that drivers were accurate in determining whether the distance between their car and a lead car was increasing or decreasing, but tended to underestimate the relative speed differential between their car and the one in front of it. In a similar experiment, Braunstein and Laughery (67) found that drivers responded to the occurrence of acceleration and deceleration rather than the magnitude.

Several early studies, such as those of Hoppe and Lauer (68) and Stalder and Lauer (69), directed themselves to the perception of motion between vehicles under reduced and night visibility conditions. These studies showed that better visibility makes it easier to perceive whether a car is coming toward one or going away from one, and also that the greater the speed the more difficult it is to perceive speed, all other things being equal.

Several studies were directed toward gap and following distance. Wright and Sleight (70) discussed the "rule of ten," calling for one car length spacing for each 10 miles of speed, and characterized it as being unrealistic. A later experiment by Lerner et al. (71) attempted to determine how following distance on the highway was affected by day versus night, trip duration, traffic, and speed. They found that the only factor of the four tested that affected following distance was speed, with greater following distances found at higher speeds. Several investigators attempted to provide displays to give the driver aided gap information. Bierley (72) tested two types of vehicle spacing visual displays. One provided the actual distance between the driver and a lead car, and the other provided the algebraic sum of the gap and the relative vehicle speed. He found that the latter display increased spacing stability. Fenton (73) proposed a tactile display for gap information that used the same principle that Bierley's algebraic summing display used. Both of these displays offer significant improvement over the present, unaided means of determining gaps.

Another group of experiments was directed toward the ability of drivers to make judgments in passing situations. Bjorkman (74) reported an experiment designed to determine how accurately a driver is able to estimate where he will meet an oncoming car. He found that subjects made errors toward the midpoint between the two cars rather than the actual meeting point, which he felt could be fatal in overtaking situations. In an experiment (75) designed to determine how well a driver can decide whether to pass a lead car, Crawford found that more than 8 percent of the time the drivers were wrong. Jones and Heimstra (76) performed a study to determine how accurately drivers could estimate the "clearance time" required to pass another car (by "clearance time" they were referring to the last possible moment that drivers could make a passing maneuver). They concluded that drivers could not make this judgment accurately.

Other traffic information needs reported cover diverse topics. Brown (77) indicated that a car radio seemed to have a beneficial rather than a detrimental effect on driving in both "light" and "heavy" traffic. Hulbert (78) attempted to determine whether driver Galvanic Skin Reactions (GSR's) could be used to record traffic events; his results indicated that they could not be used. A similar finding was made by Taylor (79) who attempted to correlate drivers' GSR's and accident rate, with negative results.

Fināāly, several studies on intervehicle communication were performed. For example, Shore (80) speaks of nonverbal expectations as a means of intervehicular communications, and develops the thesis that confusion in driving in traffic results from misinterpretation of other drivers' intentions due to different driving patterns in different locations.

Although much work has been accomplished, or is still in progress, in the area of traffic information needs, several areas still require research. More research on intervehicular communications is in order, as is research on perception of rear traffic.

Macroperformance.-In terms of vehicle control, the subactivities of the microperformance and situational performance levels fully define all possible control tasks. However, they do not fully define the driving task. A third performance level, macroperformance, completes the description of the driving task. Considerations of trip preparation and direction finding are the main subtasks of the macroperformance level. Activities at the macroperformance level are cognitive and can be performed by a "copilot," which frequently occurs. With a driver in a vehicle on a road that has curves, grades, exits, entrances, traffic, etc., it must be assumed that there is some purpose for driving-that being the desire to get from one point to another. Therefore, the macroperformance level can be viewed as the overriding director of the microperformance and situational performance levels, and can be seen to have a major effect on the manner in which the microperformance and situational performance control tasks are implemented. For example, a driver in a hurry may accept a smaller gap than he would when not in a hurry. With the introduction of the macroperformance level, the
hypothetical case is complete, for there is now a full description of the driving task for the highway system of today and that of the foreseeable future; that is, there is a driver in a vehicle, which may have other occupants, on a road that has geometric features, exits, entrances, interchanges, and an external environment. There are other drivers in other cars on this road. The road that the driver is on is, in turn, part of an existing highway system consisting of other roads, traffic, environment, etc. This system has a myriad of exits, entrances, interchanges, origins, destinations, links, and nodes. It is at the macroperformance level that the driver must plan the strategy that will enable him to move his vehicle efficiently through this system to his destination.

The macroperformance level consists of two distinct phases: (1) trip preparation and planning, which is usually a pretrip activity, and (2) direction finding, which occurs while in transit.

Trip Preparation and Planning.-Drivers use various means to formulate trip plans, depending on experience, pretrip sources, and the nature of the trip. The means can be as formal as having the trip planned by a touring service, or as simple as using a route used previously. It may consist of a driver reading existing maps and formulating the trip on his own, or receiving verbal instructions, or having a conceptualization, however vague, of where his destination is in relation to known routes and past experience, with the driver hoping for directional signs that will lead him to his destination. However minimal the preparation, it is unlikely that a driver will attempt to get to some destination completely unprepared.

The results of the direction finding task analysis have shown the importance of good trip preparation. It can be stated that the better prepared the driver is, the easier will be his direction finding task, regardless of how poor the in-trip directional information is. (The direction finding task analysis implemented by this project has shown just how poor it can be, and also how poor pretrip information sources can be.)

Direction Finding.-During the direction finding phase of macroperformance, the driver on the road must find his destination in the highway system in accordance with his trip plan and the directional information received in transit. It must be remembered that he will always be performing microperformance-level tasks and will be modifying the microperformance control behavior due to situations that may arise in transit. He must now share microperformance-level and situational-performance level subtasks with his macroperformance activity. The macroperformance task is further complicated because the information needed at this level is not necessarily purely directional, but may include consideration of such things as availability of services, and availability of alternate routes Needs of the driver and/or his passengers that may arise in transit are also part of the macroperformance level.

Conversely, microperformance and situational performance factors can affect the macroperformance level. For example, the microperformance factor of a vehicle malfunction can lead to the macroperformance activity of finding available emergency service. A situational example
would be finding a road with the level of service of $E$ or $F$ that would lead to the macroperformance activity of finding an alternate route. The manner in which the driver accomplishes the in-transit phase of the macroperformance level is entirely cognitive. He searches for, or has his attention drawn to, macroperformance information that he compares with his trip plan to decide what control, if any, is required.

In-trip presentation of macroperformance information is primarily by means of guide and service signs. However, receipt of information from in-trip sources other than signs (landmarks, service stations, billboards, etc.) is possible.

Because information received from guide and service signs is verbal or symbolic, the cognitive level required for macroperformance behavior is the highest, being almost entirely verbal and abstract and requiring digital-type, go, no-go decisions.

## Primacy

Examination of individual needs showed that some needs are obviously more important than others and that in situations where needs compete, there is an order defining the need to be satisfied first. Further analysis showed that this order is applicable not only to individual needs, but also to the three levels of performance.

For example, take a driver going from Washington, D.C., to New York via I-95. Throughout the task, assuming a free-flowing traffic pattern, he is not concentrating on his microperformance needs and is able to manipulate his vehicle in the traffic stream and attend to directional signs in transit. Now, introduce another element into the situation, such as a car cutting him off. This acts both backward along the hierarchy by intensifying the microperformance information needs, and forward by dulling the macroperformance information needs. When the other car cuts him off, he becomes totally unconcerned about what exit leads to the New Jersey Turnpike; on the other hand, microperformance information needs, such as his vehicle's rate of deceleration and lateral placement, become extremely important.

This relationship is labeled "primacy" and its characteristics are discussed in the following.

Primacy of Microperformance.-In the discussion of performance levels, the case of a driver on an empty road was used as the starting point. From this, it was shown how various elements of the highway system introduce disturbances into the driving task. It was shown that, at the microperformance level, only two main control sub-tasks-tracking and speed control-make up the driving control task. Therefore, the information needed to perform these subtasks is the most important information need, and thus assumes the highest primacy.

As the various elements of the highway system introduce complexity into the driving task, it becomes necessary for the driver to control his vehicle and keep it on the road, no matter how complex and demanding the driving task became. In "Driver Information Processing Characteristics," which follows, it is shown how little time is spent, under ideal circumstances, attending to microperformance
information. The importance of this cannot be underestimated, especially in demanding situations when the driver is required to perform complex situational performance and macroperformance tasks (as in the case of negotiating a complex urban interchange). In these, the driver must have available at all times the microperformance information needed to maintain tracking and speed control, even though he may use it only a small percentage of the time. If the microperformance information needs were not satisfied continuously, the driver would be required to spend more time searching for and attending to microperformance information, to the detriment of his situational and macroperformance tasks.

Two factors enter into the question of satisfying microperformance information needs: (1) the control demands of the microperformance level, and (2) the adequacy of information. The less demanding the microperformance task is, the easier will be the control activities. Thus, a car in proper operating condition on a good straight road will impose little in the way of control complexity and, therefore, will simplify the microperformance tasks. Conversely, a car that handles poorly or a road that is poorly designed from a geometric standpoint will intensify the microperformance tasks and cause the driver to attend more to the microperformance than should be the case. Likewise, the more adequate the presentation of information needed to perform the microperformance tasks, the easier will be the control activities. If the driver is unable to determine his location relative to the boundaries of the road and perceive which way the road is going at any time, he will be less able to maintain control and might run off the road, or have to spend too much time searching for microperformance information.

Primacy of Situational Performance.-The next information needs are those associated with the road situational performance category. In practice, it is frequently impossible to differentiate road microperformance needs from road situational performance needs, except in terms of intensity and/or degree of complexity. Therefore, these two have been combined as road microsituational information and thus establish the transition between the two levels of performance.

Slightly lower on the primacy scale are information needs associated with traffic situational performance. Following from the development of the example set forth in the level of performance discussion, it can be seen that other vehicles introduce perturbations into the driving task, which can require modifications in established vehicle control behavior. The driver not only must maintain an awareness of how he is traveling relative to the road, but he must also be aware of this relation to other moving elements of the highway system. The reason that traffic situational performance assumes a slightly lower primacy than road situational performance is that the road is always there and must be fully considered at all times, whereas other cars may not be on the road, and need be considered only when their presence requires immediate or impending action by the driver-that is, when they impinge on the driver's "area of safe travel."

Primacy of Macroperformance.-Lowest on the pri-
macy scale are macroperformance needs. The first reason is that a macroperformance failure is not as catastrophic as a microperformance or situational performance failure. Although getting lost or missing an exit represents a driver error, the resultant failure need not be catastrophic.

Another reason for the low primacy of macroperformance information needs involves the infrequent occurrence relative to the continuous microperformance and frequent situational performance information needs. Because of the infrequent occurrence, it is possible to present macroperformance information before it is actually needed, thus leaving the driver free to attend to the more important microperformance and situational performance information needs.

The third reason for the low primacy is that most of the macroperformance information needs are, or should be, satisfied prior to driving and, therefore, should not exist as needs. The primary reason that service-related macroperformance needs take precedence over directional macroperformance information needs is that service-related needs are more apt to occur in transit.

In summary, the concept of primacy derives directly from the levels of performance and provides the traffic engineer with the means for determining which information needs should be immediately satisfied for a given situation in which information needs are likely to compete. The hierarchy shown in Figure 1 presents a scale for ordering information in terms of its primacy.

Objective and Subjective Primacy.-It is important to note that there are two kinds of primacy. The first, objective primacy, determines the relative importance of competing events on the highway system that require the driver's attention. This kind of primacy is described in the preceding paragraphs.

The second, subjective primacy, is driver established. By placing the focus of his attention on one particular information source, the driver is tacitly indicating that that particular source is providing the most important information at the moment. The degree to which objective and subjective primacy coincide is a measure of the success of an information system design. The driver who establishes a primacy that is not in agreement with the objective primacy is placing himself in a potentially dangerous position. Diverting attention from a rapidly diminishing gap to a sign for route information is indicative of poor subjective primacy. A well-designed information system would attract the driver's attention to the primary need when competing needs exist and release his attention when the need is satisfied.

Conclusion.-The concept of primacy is a powerful tool for evaluating where particular information needs should be presented. This assumes that the personnel applying the concept consider each situation and develop an applicable primacy scale.

## Inventory of Information Needs

Information needs were categorized in accordance with the information inputs to the driver, which were theoretically established by the Driver Transfer Function and Driving Task Model. The results of this categorization were com-
bined with the levels of performance breakdown to provide eight discrete categories of information need. Each category derives its name from its place in the levels of performance and the subject of that information:

1. Vehicle microperformance.
2. ARI microperformance.*
3. Road microsituational performance.
4. Traffic situational.
5. ARI situational.
6. Service macroperformance.
7. Directional macroperformance.
8. ARI macroperformance.

Tables 3 to 10 summarize the results of the synthesis. It must be emphasized that this inventory does not represent the universe of needs; the needs listed and defined were developed from the analyses of field trips. Appendix A describes the procedures and constraints of these analyses.

The inventory of needs is structured according to the primacy concept. Tables 3 to 10 correspond, in descending primacy rank, to the eight categories developed from the hierarchy. Within each table, the needs are presented in descending order in terms of their "within-category" primacy rankings.

The last column in each table lists the existing means of transmission for each need and the sensory channel presently used to receive this information. Information needs that are satisfied by the driver's ability to use inferential logic are not included. An example of such inference would be the perception of a sTOP AHEAD sign, indicating an at-grade junction (road microsituational) and cross traffic (traffic situational).

## Driver Information Processing Characteristics

Previous sections describe: (1) the results of the human factors activities and the task analysis in terms of the tasks that the driver is required to perform in order to drive, and (2) the information that the driver needs to perform these control tasks. This section deals with the principal factors underlying the reception and use of the information needed by the driver.

To determine the principal factors of reception and use, the way in which drivers receive and use information was analyzed within the context of the levels of performance and primacy concepts. The analysis was made for drivers in general, to determine the characteristics that highway users have in common. Following this analysis of the commonality of drivers, some worst-case drivers are considered to develop a systematic presentation of needed information, which has the capabilities of accommodating all legally licensed highway users.

To facilitate this discussion, a distinction is made between reception and processing. Reception relates to the sensory receptor mechanisms involved in the receipt of information by the driver; processing relates to the mental activities involved in making decisions based on received

[^7]information. Although it is possible to discuss reception and information processing as if they were separate entities, they are interrelated (81).

Information processing covers the following categories:

1. What the driver brings into the driving task-that is, a priori knowledge.
2. How the driver obtains and uses information in transit-that is, signal search, detection, and decision making.

## A Priori Knowledge

It is evident that the driver brings a body of knowledge, experience, and skills to the driving task. This a priori information is supplemented by the information acquired in preparation for a specific trip.

General Background.-Educational level and everyday experience are primary contributions to a driver's general background.

Because the discussion is for a median-case driver (described in Chapter One), it can be postulated that he possesses a tenth-grade education. Therefore, it can be assumed that he can add, subtract, deal in fractions, and read and comprehend simple English. Because his IQ level is 100 , he can comprehend and deal with simple symbols and abstractions.
It is not possible to determine the contribution of everyday experience, except to indicate that population expectancies (82) exist, which form part of a driver's a priori information store.

Driving Experience.-Cumming (16) analyzed the skills needed to operate a motor vehicle, and developed the thesis that driving a car requires that the driver learn, through experience, how to divide his attention between many information sources so as to obtain an appreciation of a dynamically changing environment. He shows how the novice driver is unable to perform his speed control tasks smoothly until he has completely integrated the skills of vehicle control and signal search. He contrasts the beginning driver with the experienced driver and shows how the experienced driver has developed the skill of information gathering so that he is able to time-share by inferring and predicting on the basis of short glances at many information sources. This point is amplified in the next section where signal search and detection are discussed. A priori knowledge gained by experience must be brought to the driving task by the driver so that he can drive safely and efficiently.
The importance of experience can be inferred from statistics (10) that show that the young driver (under age 20 ), who constitutes 10 percent of the driving population, accounts for 17 percent of all accidents, whereas the median driver (age 35 to 39 ), who also constitutes about 10 percent of the driving population, accounts for about 8 percent of all accidents. Because the young driver is better equipped physically, part of the disparity of accidents may be attributed to experience.

In the discussion of the driving task, the control skills are delineated without considering that the driver must receive information and know what to do with it on

TABLE 3
VEHICLE-MICROPERFORMANCE INFORMATION NEEDS

| ITEM | information need | Definition | PRESENT MEANS OF RECEPTION AND TRANSMISSION |
| :---: | :---: | :---: | :---: |
| 1 | Vehicle handling characteristics (Type Need) | Information relating to vehicle handling (acceleration, braking, steering, ride, cornering, etc.) under all conditions. | 1. A priori-manufacturer's specifications. <br> 2. A priori-experience and learning <br> 3. Visual-perception of environment <br> 4. Visual-perception of displays <br> 5. Kinesthetic-feel of acceleration, deceleration, ride, cornering <br> 6. Tactile-feel of road via steering wheel, controls, "seat of pants," etc. <br> 7. Auditory-sound of engine, etc. |
| 2 | Vehicle handling characteristics, change in (Type Need) | Information informing driver of changes in vehicle handling and what limitations on its performance now exist (primarily degradation in performance due to aging and/or malfunctions). Also, changes in vehicle handling due to adverse road/environmental conditions or changes in loading. | Generally inferred by comparing present and past information received via 3 through 7 of Item 1 |
| 3 | Vehicle operating conditions (Type Need) | Information indicating mechanical operating condition of the car (mechanical soundness, dangerous conditions, etc.). | 1. A priori-inspection of vehicle <br> 2. Visual-perception of displays (oil pressure, temperature, ammeter) <br> 3. Auditory-sound of vehicle <br> 4. Tactile-feel of vehicle <br> 5. Kinesthetic-feel of vehicle <br> 6. Olfactory-smell of vehicle |
| 4 | Vehicle operating conditions; change (Type Need) | Information informing the driver that changes of an adverse nature have occurred in the operating condition of the vehicle that may require his immediate attention. | Determined via same means as 2 through 6 of Item 2, with more emphasis on interpretation of the gauges and nonvisual aspects |
| 5 | Lateral location | Information providing the driver with data as to where his car is in relation to the fixed boundaries of a highway. | 1. Visual-perception of fixed boundaries on highway (edges, lane markers, roadside features) <br> 2. Tactile-feel of joints, raised markers, etc. |
| 6 | Lateral location; change in | Information indicating that the vehicle has changed location from where it was to a new location in relation to the fixed boundaries of a highway. | 1. Visual-perception of change in location relative to fixed boundaries on highway (lane and edge markings, roadside features) <br> 2. Tactile-feel of joints <br> 3. Kinesthetic-feel of car moving to a different location |
| 7 | Direction, longitudinal | The direction in which the vehicle is heading, either forward or reverse, within a lane. | 1. Visual-perception of environment <br> 2. Kinesthetic-feel of motion |
| 8 | Velocity | Rate of change of distance per unit time. | 1. Visual-perception of speedometer <br> 2. Visual-perception of movement relative to visual field <br> 3. Kinesthetic-feel of speed <br> 4. Auditory-sound of engine |
| 9 | Deceleration | Negative rate of change of velocity. | 1. Visual-perception of environmental cues <br> 2. Visual-perception of change in indication on speedometer and/or tachometer <br> 3. Kinesthetic-feel of deceleration <br> 4. Auditory-sound of motor and/or squeal of tires <br> 5. Tactile-feedback via brake pedal being depressed |
| 10 | Acceleration | Positive rate of change of velocity | 1. Visual-perception of environmental cues <br> 2. Visual-perception of change in indication on speedometer and/or tachometer <br> 3. Kinesthetic-feel of acceleration <br> 4. Auditory-sound of motor and/or gears <br> 5. Tactile-feedback via gas pedal being depressed |
| 11 | Direction, longitudinal; change in | Information to the driver that his vehicle has changed directions from forward to reverse, or vice versa. | 1. Visual-perception of change in direction <br> 2. Kinesthetic-feel of change of direction |

TABLE 4
ARI-MICROPERFORMANCE INFORMATION NEEDS

| ITEM | INFORMATION NEED | DEFINITION | PRESENT MEANS OF RFCEPTION AND TRANSMISSION |
| :---: | :---: | :---: | :---: |
| 1 | ```Lack of visibility (driv- ing past sight distance) }\mp@subsup{}{}{\textrm{a} (Type Need)``` | Information indicating that rate of speed is such that minimum braking distance exceeds sight distance and is thus potentially hazardous. | 1. A priori only-no means of formal transmission |
| 2 | Regulatory speed ${ }^{\text {D }}$ (Type Need) | Legal speed allowed on specific road. | 1. Visual—perception of speed limit sign <br> 2. A priori-knowledge of speed limit |
| 3 | Speed limit; maximum ${ }^{\text {b }}$ (Specific Need) | Information indicating maximum speed. | 1. Visual-perception of sign (SPEED LIMIT 50 MPH) <br> 2. A priori_-knowledge of state maximum speed limit on unposted roads |
| 4 | Speed limit; advisory (Specific Need) | Information indicating maximum safe speed at a specific location. | 1. Visual-perception of sign (ramp speed 30 MPH) |
| 5 | Speed limit; minimum " (Specific Need) | Information indicating minimum speed. | 1. Visual-perception of signs (MINIMUM SPEED Limir 40 MPH ) <br> 2. A priori-knowledge of minimum speed limit for unposted road |
| 6 | Climatological conditions ${ }^{\mathrm{b}, \mathrm{c}}$ | Information, in advance, indicating prevailing or expected climatological conditions | See specific needs |
| 7 | Fog ${ }^{\text {b, a }}$ (Specific Need) | Information, in advance, indicating that the driver is approaching fog, which will require that he modify his driving. | 1. Visual-perception of fog <br> 2. Visual-perception of signs (fog in lowlying areas) <br> 3. Auditory-commercial radio |
| 8 | Wind ${ }^{b, a}$ (Specific Need) | Information, in advance, informing the driver that he is in or approaching a high wind situation, which will require that he modify his driving patterns. | 1. Visual-perception of effect of wind <br> 2. Auditory-commercial radio <br> 3. Kinesthetic-Tacile-feel of wind while driving |
| 9 | Rain ${ }^{\text {b, " }}$ (Specific <br> Need) | Information, in advance, informing the driver that he is in or approaching a rain situation of sufficient severity to require that he modify his driving patterns. | 1. Visual-perception of rain <br> 2. Auditory-commercial radio |
| 10 | Snow ${ }^{1,1}$ (Specific Type) | Information, in advance, informing the driver that he is in or approaching a snow situation of sufficient severity to require that he modify his driving patterns. | 1. Visual-perception of snow <br> 2. Auditory-commercial radio <br> 3. A priori-knowledge of snow conditions (as in Minn., Maine, Canada, etc.) |
| 11 | Sleet ${ }^{1,}{ }^{\text {d }}$ (Specific Type) | Information, in advance, informing the driver that he is in or approaching a sleet situation of sufficient severity to require that he modify his driving patterns. | 1. Visual perception of sleet <br> 2. Auditory-commercial radio |

${ }^{\text {a }}$ There are information needs similar to this, that affect microperformance behavior and are physiologically or psychologically induced (fatigued drunk, drugged, etc.); these are not within the scope of this project.
Certain information needs can be assigned to more than one category. When such is the case, the need will be included only in its highest primacy location.
"The optimum condition is the "null" case of the "type need."
${ }^{a}$ Advanced warning of condition.
receipt. A priori driving knowledge consists not only of the skill of gathering information, but also of the experience of knowing how to use the information, once gathered.

The a priori knowledge so far discussed specifically relates to the microperformance and situational performance levels of driving behavior. However, driving also contains a macroperformance level (direction finding).

It must be assumed that the highway user starts with: (1) the ability to operate a motor vehicle, (2) the basic knowledge of laws and rules necessary to obtain a driver's license, and (3) more or less specific information about his trip destination. The degree of knowledge and ability in other fields, examples of which are listed, is more uncertain and should be investigated:

1. General knowledge of geography. Distance and di-

TABLE 5
ROAD-MICROSITUATIONAL INFORMATION NEEDS

| ITEM | INFORMATION NEED | DEFInition | PRESENT MEANS OF RECEPTION AND TRANSMISSION |
| :---: | :---: | :---: | :---: |
| 1 | Alignment, horizontal * (Type Need) | Information indicating road curves in the horizontal planc. | 1. Visual-perception of geometry of road <br> 2. Visual-perception of lane markers, edge markers, delineators, etc. <br> 3. Visual-perception of signs (CURVE, etc.) |
| 2 | Alignment, horizontal; change in (Type Need) | Information indicating a horizontal alignment change and degree of change. | 1. Visual-perception of geometry of road <br> 2. Visual-perception of lane markers, edge markers, delineators, etc. <br> 3. Visual-perception of signs (CURVE ahead) <br> 4. Tactile feedback-via steering wheel <br> 5. Kinesthetic-feedback <br> 6. A priori-knowledge of road alignment |
| 3 | Alignment, vertical ${ }^{\text {a }}$ (Type Need) | Information indicating road curves in the vertical plane. | 1. Visual-perception of geometry of road <br> 2. Visual-perception of signs (hill, etc.) <br> 3. Visual-perception of topography |
| 4 | Alignment, vertical; change in (Type Need) | Information indicating a grade change and degree of change. | 1. Visual-perception of geometry of road <br> 2. Visual-perception of signs (steep hill) <br> 3. Tactile feedback-via brake (downhill) or accelerator (uphill) <br> 4. Kinesthetic-feedback <br> 5. A priori-knowledge of road alignment |
| 5 | Surface, climatological ${ }^{\mathrm{a}, \mathrm{b}, \mathrm{c}}$ (Type Need) | Information indicating road surface condition (free of water, dry, wet, icy, etc.) due to climatological conditions. | 1. Visual—perception of road surface <br> 2. Tactile-feedback from road surface |
| 6 | Surface, climatological; icy ${ }^{a, b,}{ }^{\text {b }}$ (Specific Need) | Information indicating that road surface is icy. | 1. Visual-perception of icy surface <br> 2. Visual-perception of signs (bridge freezes before roadway) <br> 3. Tactile-feedback or lack thereof <br> 4. Auditory-commercial radio reports |
| 7 | Surface, climatological; snow ${ }^{\text {n, b, a }}$ (Specific Need) | Information indicating that road surface is snowy. | 1. Visual-perception of snowy surface <br> 2. Tactile feedback or lack therenf <br> 3. Auditory-commercial radio reports |
| 8 | Surface, climatological; wet ${ }^{\text {a, }, \mathbf{b}, \mathbf{d}}$ (Specific Need) | Information indicating that road suface is wet. | 1. Visual-perception of wet surface <br> 2. Tactile-feedback or lack thereof <br> 3. Auditory-commercial radio reports <br> 4. Visual-perception of conditions that will result in wet surface |
| 9 | Surface, structural ${ }^{\text {c }}$ (Type Need) | Information indicating road surface structural condition (free of potholes, bumps, broken spots, etc.). | 1. Visual-perception of smooth road surface <br> 2. Tactile-feedback from road surface <br> 3. Visual-perception of signs (bump) |
| 10 | Surface, type; change in (Type Need) | Information indicating that the type of road surface has changed or will change from one type to another (dirt to concrete; asphalt to bridge grid; etc.). | 1. Visual-perception of change in road surface <br> 2. Visual-perception of signs (Dirt road ahead) <br> 3. Tactile-feel of road surface change <br> 4. A priori-road map indicating dirt road |
| 11 | Surface, structural; change in (Type Need) | Information indicating that the structural road surface has changed or will change from one condition to another (smooth to broken, etc.). | 1. Visual-perception of change in structural conditions <br> 2. Visual-perception of sign (broken paveMENT) <br> 3. Tactile-feedback via vehicle <br> 4. A priori-maps, etc. |
| 12 | Surface, structural; bump (Specific Need) | Information indicating that road surface has a bump. | 1. Visual-perception of bump <br> 2. Visual-perception of sign (BUMP) <br> 3. Visual-observation of vehicles traversing bump |
| 13 | Surface, structural; foreign objects on surface (Specific Need) | Information indicating that foreign objects (rocks, debris, etc.) are on road surface. | 1. Visual-perception of foreign objects <br> 2. Visual-perception of sign (fallen rock ZONE) <br> 3. Tactile-feedback via vehicle |
| 14 | Surface, structural; broken (Specific Need) | Information indicating that road surface is broken (cracks, holes, etc.). | 1. Visual-visual perception of broken surface <br> 2. Visual-perception of sign (broken pavement) |
| 15 | Surface, climatological; change in (Type Need) | Information indicating that road surface has changed or will change from one condition to another. | 1. Visual-perception of change in road surface condition <br> 2. Visual-perception of signs (bridge freezes before roadway) <br> 3. Tactile-feedback or lack thereof <br> 4. Auditory-commercial radio reports |


| ITEM | INFORMATION NEED | definition | PRESENT MEANS OF RECEPTION AND TRANSMISSION |
| :---: | :---: | :---: | :---: |
| 16 | Lanes; width of (Type Need) | Information indicating relative width lane. | 1. Visual-perception of lane width via lane markers, etc. |
| 17 | Cross section; change of (Type Need) | Information indicating that a change in the cross section has occurred or will occur (change in quantity or width of lanes; change in median or shoulder configuration; ctc.). | 1. Visual-perception of changes in cross section <br> 2. Visual-perception of signs (Divided high. . WAY ENDS) <br> 3. A priori-maps, etc. |
| 18 | Median; details ${ }^{\text {a, }}$ c <br> (Type Need) | Information indicating absence and/ or presence of median and also type (barrier or mountable, width, etc.). | 1. Visual-perception of median (or lack thereof) <br> 2. Visual-perception of signs (divided road ahead) |
| 19 | Shoulder; details ${ }^{\text {a, f }}$ (Type Need) | Information to the driver about absence and/or presence of shoulder and also type (surfaced, stabilized, etc.; width, etc.). | 1. Visual-perception of shoulder <br> 2. Visual-perception of signs (soft Shoulder) |
| 20 | Ditches a, e | Information indicating absence and/or presence of ditches and their location. | 1. Visual-perception of ditches <br> 2. Visual-perception of signs (DITCH) |
| 21 | Surface, type (Type Need) | Information indicating road type (concrete, dirt, etc.). | 1. Visual-perception of dirt road <br> 2. Visual-perception of sign (Dirt road) <br> 3. Tactile-feedback of road <br> 4. A priori-road map indicating dirt road |
| 22 | Obstacles; roadside (cross section) | Information indicating absence and/or presence of roadside obstacles (trees, signs, fences, light poles) and their location. | 1. Visual-perception of obstacles |
| 23 | Lanes; no. of (cross section) (Type Need) | Information indicating quantity of lanes on road (usable by the driver). | 1. Visual-perception of lanes via lane markers <br> 2. Visual-perception of signs (three-lane road ahead) <br> 3. A priori-from road map |
| 24 | Intersection, at-grade (Specific Need) | Information indicating that an "at-grade" (same level of roadway) intersection is approaching, and details of configuration of intersection. | 1. Visual-perception of intersection <br> 2. Visual-perception of signs (symbolic displays of intersection configurations, INTERsection ahead) <br> 3. A priori-from maps, etc. |
| 25 | Intersection; railroad crossing (Specific Need) | Information indicating that an "at-grade" railroad crossing is ahead and whether a train is coming. | 1. Visual-perception of railroad crossing configuration <br> 2. Visual-perception of signals and signs (RR crossing ) <br> 3. Auditory-perception of bells, etc. |
| 26 | Special features; detours (Type Need) | Information indicating that a detour is ahead and what to do. | 1. Visual-perception of physical signs of detour (barricades, lamps, etc.) <br> 2. Visual-perception of signs (Detour ahead) <br> 3. A priori-maps, etc. |
| 27 | Special features; construction (includes all road work) (Type Need) | Information indicating that construction is ahead and what to do. Differs from detour inasmuch as driver does not leave the road. | 1. Visual-perception of physical signs of construction (flagmen, equipment, lamps, etc.) <br> 2. Visual-perception of signs (CONSTRUCTION aHEAD) <br> 3. A priori-maps, etc. |
| 28 | Road environment; change in ${ }^{15}$ (Type Need) | Information indicating that the road environment (from elevated to level, from bridge to tunnel, etc.) has changed or will change. | 1. Visual-perception of change in road environment <br> 2. Visual-perception of signs (bridge ahead) <br> 3. A priori-determined from maps |
| 29 | Bridges (Specific Need) | Information indicating that a bridge is being approached (which may require modification of driving behavior). | 1. Visual-perception of bridge <br> 2. Visual-perception of signs (george washington bridge) <br> 3. A priori-road map indicating bridge |
| 30 | Tunnel (Specific Need) | Information indicating that a tunnel is being approached (which may require modification of driving behavior). | 1. Visual-perception of tunnel <br> 2. Visual-perception of signs (LINCOLN TUNNEL) <br> 3. A priori-road map indicating tunnel |

[^8]TABLE 6
TRAFFIC-SITUATIONAL PERFORMANCE INFORMATION NEEDS

| ITEM | INFORMATION NEED | Definition |
| :---: | :---: | :---: |
| 1 | In-lane traffic; speed of (lead) (Type Need) | Information indicating speed of vehicles in driver's lane (lead vehicle and beyond). |
| 2 | Gap; front (Type Need) | Information indicating (qualitative or quantitative) distance between driver's car and the lead car. |
| 3 | Gap, front; change in ${ }^{\text {a }}$ (Type Need) | Information indicating (qualitative or quantitative) the occurrence, and rate ( + or - ) of change of distance between driver's car and the lead car. |
| 4 | In-lane traffic behavior; lead (Type Need) | Indications of what the lead traffic will do (stop, speed up, turn, etc.). |
| 5 | In-lane lead traffic speed; change in ${ }^{\text {a }}$ (Type Need) | Indication (qualitative or quantitative) of the occurrence and rate ( + or - ) of change of speed between driver's car and lead vehicle. |
| 6 | Adjoining lane traffic; lateral placement (Type Need) | Indication of presence and location (left and/or right) of traffic in adjoining lanes. |
| 7 | Adjoining lane traffic; speed (Type Need) | Indication of rate of speed of vehicle(s) in adjoining lane(s) (left and right). |
| 8 | Adjoining lane traffic behavior; lead ${ }^{\text {b }}$ (Type Need) | Indication of what the lead traffic in the adjoining lanes will do (stop, speed up, cut in, etc.). |
| 9 | Adjoining lane traffic behavior; rear " (Type Ne.ed) | Indication of what traffic in rear adjoining lanes will do (stop, speed up, cut in, etc.). |
| 10 | Adjoining lane traffic; lag ${ }^{\text {c }}$ (Type Need) | Indication of remaining gap alongside driver (for passing). |
| 11 | Adjoining lane traffic; lag; change in ${ }^{\text {a }}$ (Type Need) | Indication of the occurrence and rate ( + or - ) of change of remaining gap alongside driver (for passing). |
| 12 | Adjoining lane traffic; being passed by (Type Need) | Indication that driver is being passed by vehicle(s) in adjoining lane(s). |
| 13 | Adjoining lane traffic; passing (Type Need) | Indication that driver is passing vehicle(s) in adjoining lane(s). |
| 14 | Gap; rear (Type Need) | Indication (qualitative or quantitative) of the distance between his rear and the rear car's front. |
| 15 | Gap, rear; change in ${ }^{\text {a }}$ (Type Need) | Indication (qualitative or quantitative) of the occurrence and rate $(+$ or - ) of change of rear gap. |
| 16 | In-lane traffic behavior; rear " (Type Need) | Indication of what rear traffic in driver's lane will do (speed up, cut out of lane, etc.). |
| 17 | Oncoming traffic; distance to ${ }^{\text {a }}$ (Type Need) | Indication of how far driver is (quantitatively or relatively) from oncoming traffic. |
| 18 | Oncoming traffic; distance to; rate of change of " (Type Need) | Indication of how fast the distance between driver's car and oncoming car(s) is changing. |

PRESENT MEANS OF RECEPTION AND TRANSMISSION

1. Visual-perception of lead vehicle(s) and estimation of speed relative to speed of own vehicle.
2. Visual-perception of lead vehicle(s) and estimation of gap.
3. Visual-perception of lead vehicle(s) and estimation of rate of change of gap
4. Visual-perception of lead vehicle(s) tail lights, turn signals, etc.
5. Visual-perception of lead vehicle(s) and estimation of rate of change of speed.
6. Visual-perception of lateral traffic placement by viewing traffic in relation to lane marker, etc.
7. Auditory-sound of lateral traffic.
8. Visual-perception of lateral traffic speed by estimation to own speed.
9. Visual-perception of adjoining lane(s) lead vehicle's turn signals, tail lights, etc.
10. Visual-perception of rear vehicle(s) turn signals, lights, etc.
11. Visual-based on perception of lag.
12. Visual-based on perception of rate of change of lag.
13. Visual-perception of traffic passing.
14. Auditory - sound of traffic passing.
15. Visual-perception of passing traffic.
16. Auditory-sound of passing traffic.
17. Visual-perception of rear gap.
18. Visual-perception of rate of change of rear gap.
19. Visual-perception of rear vehicle(s) turn signals, lights, etc. (also aural-horn).
20. Visual-perception of oncoming traffic and distance to.
21. Visual-merception of rate of change of distance to oncoming traffic.

| ITEM | Information need | DEFINITION | Present means of reception and transmission |
| :---: | :---: | :---: | :---: |
| 19 | Oncoming traffic; speed ${ }^{\text {" }}$ (Type Need) | Indication of speed of oncoming traffic. | 1. Visual--perception of speed of oncoming traffic. |
| 20 | Oncoming traffic: speed; rate of change " Type Need) | Indication of whether and how much ( 1 or - ) the speed of oncoming traffic is changing. | 1. Visual-perception of rate of change of speed of oncoming traffic. |
| 21 | Oncoming traffic behavior ${ }^{\text {" }}$ (Type Need) | Indication of what oncoming traffic will do (stop, cut into lane, turn in front of). | 1. Visual-perception of oncoming traffic's turn signals, lights, etc. |
| 22 | Oncoming traffic; volume ${ }^{\text {d }}$ (Type Need) | Indication of how many vehicles are approaching. | 1. Visual-perception of oncoming traffic density. |
| 23 | Cross traffic; distance to ${ }^{\text {e }}$ <br> (Type Need) | Indication of how far driver's vehicle is from cross traffic. | 1. Visual-perception of distance to cross traffic. <br> 2. Visual-signs (driveway 500 feet) |
| 24 | Cross traffic; distance rate of closure ${ }^{\text {e }}$ (Type Need) | Indication of how fast the distance between driver's vehicle and cross traffic is closing. | 1. Visual-perception of rate of closure of distance to cross traffic. |
| 25 | Cross traffic; speed of ${ }^{\text {c }}$ (Type Need) | Indication of speed of cross traffic. | 1. Visual-perception of speed of cross traffic. |
| 26 | Cross traffic; speed of; rate of change of ${ }^{e}$ (Type Need) | Indication of $(+$ or - ) the rate of change of speed of cross traffic. | 1. Visual-perception of rate of change of speed of cross traffic. |
| 27 | Cross traffic behavior (Type Need) | Indication of what cross traffic will do (stop, turn, speed up, etc.). | 1. Visual-perception of cross traffic turn signals, lights, etc. |
| 28 | Level of service (Type Need) | Indication of type of traffic flow ahead (volume, density, speed relationship) in terms of his degrees of freedom of travel (change lanes freely, travel freely in own lane, all lanes slow, etc.). | 1. Visual-perception of traffic. <br> 2. Auditory-commercial radio reports. |

${ }^{a}$ Also rate of change (qualitative).
b Information indicating traffic merging into lane of driver also included.
c Information indicating driver merging into lane of traffic also included.
d Applicable to undivided roads.
e Applicable to at grade intersections.
rection relationship of destination to origin and of destination to nearest prominent landmark or town.
2. Ability to read a map. Knowledge of where to obtain maps, and knowledge (in relation to item 1) of which maps to obtain.
3. Ability to understand compass direction. Ability to translate changes of course into driving maneuvers (e.g., westbound to northbound requires a right turn).
4. Ability to understand weather reports and translate them into roadway and visibility conditions.
5. Ability to translate distance into driving time under prevailing conditions.
6. Degree of familiarity with highway and interchange types and elements.

Trip Planning and Preparation.-The third category of a priori knowledge that the driver takes into the driving task involves the specific knowledge acquired by the driver in preparing his specific trip plan. This discussion is limited to noncommuting-type trips, although it is recognized that there are elements of trip planning and preparation that go into commuting trips (e.g., a driver may hear
that his particular commuting route is jammed due to an accident and therefore may take some alternate route).

The trip planning and preparation a priori knowledge acquisition phase is devoted almost entirely to the gathering of macroperformance information. However, certain aspects of microperformance and situational performance needs enter into the picture. Such things as advance weather information, traffic, condition of the driver's car, and types of roads can contribute to the final trip plan formulated and may play a major role in determining whether a formulated trip plan is modified or aborted in transit. A driver generally has some sort of trip plan as part of his a priori knowledge store. It must be stressed that few data are available to gauge the adequacy of any trip plan or how it is used by the driver in transit. More research is needed in the area of trip planning and preparation.

## Signal Search, Detection, and Recognition, and Decision Making

Hulbert (14) cites evidence showing that a driver can attend to only one information source at a time. The

TABLE 7
ARI-SITUATIONAL PERFORMANCE INFORMATION NEEDS

| ITEM | Information need | DEFINITION | Present means of reception and transmission |
| :---: | :---: | :---: | :---: |
| 1 | Regulatory; all situational need | Indication of what driver must do by law, ordinance, or regulation. | See all Regulatory "Specific Need" below |
| 2 | Regulatory; stop (Specific Need) | Information that driver must stop and where. | 1. Visual-perception of stop signs, traffic signals, flashing red lights, etc. <br> 2. Visual-perception of signs (STOP ahead) <br> 3. A priori-(varies by state and situation) <br> 4. Visual-observe traffic officer's gestures <br> 5. Auditory-hear police whistle |
| 3 | Regulatory; no passing (Specific Need) | Indication that driver is approaching or is in a situation where he is not permitted to pass other vehicles. | 1. Visual-perception of signs (No passing). <br> 2. Visual-perception of yellow line in lane <br> 3. A priori-prior knowledge of types of location where passing is prohibited |
| 4 | Regulatory; yield right of way (Specific Need) | Indication that driver is approaching a situation where he is required to yield the right-of-way to all other traffic. | 1. Visual-perception of yield right of way signs <br> 2. A priori-prior knowledge of specific situations where yielding is required <br> 3. A priori-general knowledge ("Rules of the Road") |
| 5 | Regulatory; one-way street (Specific Need) | Indication that driver is approaching or is in a street that permits traffic to flow in one direction only and what that direction is. | 1. Visual-perception of signs (one way) <br> 2. A priori-prior knowledge from maps, etc. <br> 3. Visual-perception of behavior of other traffic |
| 6 | Regulatory; no stopping (Specific Need) | Indication that driver is approaching or is in a location where he will not be permitted to stop. | 1. Visual-perception of signs (no stopping) <br> 2. A priori-prior knowledge of rules <br> 3. Visual-perception of police officer's gestures <br> 4. Visual-perception of color-coded curbs |
| 7 | Regulatory; keep in lane (Specific Need) | Indication that driver is approaching or is in a situation where he is forbidden to change his lane. | 1. Visual-perception of signs (KEEP in lane) <br> 2. Visual-perception of solid white line markings <br> 3. A priori-prior knowledge of rules |
| 8 | Regulatory; no U turn (Specific Need) | Indication that diver is approach ing or is in a location where he cannot make a U turn. | 1. Visual-perreption of signs (no u turn) <br> 2. A priori-prior knowledge of regulations |
| 9 | Regulatory; proceed with caution (Specific Need) | Indication that driver is permitted to proceed, but that he is liable to encounter a situation that may be potentially hazardous. | 1. Visual-perception of signs (proceed wirt caution) <br> 2. Visual-perception of amber signals <br> 3. Visual-perception of situation |
| 10 | Regulatory; proceed (Specific Need) | Indication that driver can proceed. | 1. Visual-perception of green signal light <br> 2. Visual-perception of police officer's gestures |
| 11 | Regulatory; speed zone; start of (Specific Need) | Indication that driver is or will be approaching a zone where the speed limit will be lower than it was prior to the start of the zone. | 1. Visual-perception of sign (SPEed zone ahead or begin - MPH SPEED) |
| 12 | Regulatory; speed zone; end of (Specific Need) | Indication that driver is or will be leaving a zone with a restricted speed limit, and that he will be able to resume normal speed (all other factors being equal). | 1. Visual-perception of signs (END — MPH SPEED) |
| 13 | Warnings; all road needs ${ }^{\text {a }}$ (Type Need) | Information cautioning driver that a situation is upcoming that may affect his driving behavior. | See all Warning "Specific Needs" |
| 14 | Warning; deer crossing (Specific Need) | Information alerting driver to possibility of deer crossing his path. | 1. Visual-perception of signs (DEER CROSSING) |
| 15 | Warning; fallen rock zone (Specific Need) | Information alerting driver to possibility of fallen rocks in his path. | 1. Visual-perception of signs (fallen rock zone) |
| 16 | Advisory; all road needs (Type Need) | Information advising driver of situation. | See all Advisory "Specific Needs" |
| 17 | Advisory; toll station upcoming | Information informing driver that toll booth is upcoming. | 1. Visual-perception of toll approaching <br> 2. Visual-perception of sign (toll ahead) <br> 3. A priori-knowledge, maps, etc. <br> 4. Tactile-rumble strip |
| 18 | Advisory; toll lane, cost, etc. (Specific Need) | Information telling the driver which toll lane is applicable to his particular circumstance. | 1. Visual-perception of signs (exáct toll center lane) |

a Driver is not required by law to act on information.

TABLE 8
SERVICE-MACROPERFORMANCE INFORMATION NEEDS

| ITEM | Information need | definition | PRESENT MEANS OF RECEPTION AND TRANSMISSION |
| :---: | :---: | :---: | :---: |
| 1 | Available services; emergency (Type Need) | Indication that emergency services are available and how to obtain them. | 1. Visual-perception of signs (USE PHONE FOR assistance) <br> 2. A priori-prior knowledge of emergency services available <br> 3. Visual-perception of police car, hospital, etc. |
| 2 | Available services ${ }^{\text {a }}$ (Type Need) | Indication of services available (or not available) on particular route. | 1. Visual-perception of signs (service area 5 miles) <br> 2. A priori-knowledge from maps, guide books, etc. <br> 3. Visual-perception of service facility |
| 3 | Gas management; qualitative + quantitative (Type Need) | Indication of how much gas driver presently has and when he will require more. | 1. Visual-perception of gas gauge <br> 2. A priori-knowledge of mpg for car |

a Includes information about where to obtain information.

TABLE 9
DIRECTIONAL-MACROPERFORMANCE INFORMATION NEEDS
$\left.\begin{array}{llll}\hline \text { ITEM } & \text { INFORMATION NEED } & \text { DEFINITION } & \text { PRESENT MEANS OF RECEPTION AND TRANSMISSION }\end{array}\right]$

[^9]TABLE 10
ARI-MACROPERFORMANCE INFORMATION NEEDS

| ITEM | INFORMATION NEED | DEFINITION | PRESENT MEANS OF RECEPTION AND TRANSMISSION |
| :--- | :--- | :--- | :--- |

analysis of the driving task has shown that there is considerable task-sharing throughout the driving task. Furthermore, it has been shown that diverse information sources compete for the driver's attention, especially in high-signal areas such as at interchanges and in urban areas. The situation is further complicated on high-speed Interstate routes where the driver is faced with time pressures as well as competing information needs and task-sharing. Therefore, the driver's ability to perform, especially in high-signal, high-speed situations, depends on his ability to time-share his attention among the competing information sources and focus his attention on the most important information needs. The driver's ability to perform is also based on the nature of the decisions that he must make. Before the concepts of decision making are considered, the concept of how the driver shares tasks is considered.

Although the driver obtains information via all of his senses, the information-gathering discussion is structured in terms of the driver's visual reception. This is done for two reasons. First, the primary source of information reception by the driver is the eye, accounting for almost 95 percent of all information received by the driver (13). Second, the visual reception channel is characterized by the fact that visual information must be attended to in order to be received.

Task Sharing.-Microperformance information-gathering activities are always being time-shared with the situa-
tional and macroperformance information-gathering activities. Although the vehicle control tasks (i.e., tracking and speed control) are not being constantly attended to, infor-mation-gathering for microperformance does require part of the driver's attention time. This point is clearly shown in the research by Senders et al. (83). If the driver does not pay attention to his microperformance, he risks running off the road or exceeding the safe speed. This implies that the attention demands placed on the driver should never reach the point where the driver is unable to devote a part of this time to microperformance needs. This is a principle that must be considered in the design of any information system. Furthermore, Stephens and Michaels (56) found that studies they reviewed on task-sharing indicated a generalized degradation of performance as task complexity increased. Because increased task complexity indicates more attention demands on the driver, the preceding principle can be expanded to include all levels of performance.

Information Gathering.-Cumming (16) states that one of the most important driving skills is the skill of systematically and efficiently gathering information. He cites studies of filmed records of driver's eye movements, which indicate a maximum rate of sampling from separate information sources of about 1 to 1.4 per second. He concludes that this scan rate is not sufficient to give the driver enough of the information that he needs. Cumming concludes that the driver relies on his short-term memory and ability
to integrate information. Expectancies are also used to fill information gaps. This concept of expectancies and their role in facilitating the driver's task is a factor that was determined by the research reported on herein and is amplified in a subsequent section of this report.

Schlesinger and Safren (65), in discussing the question of gathering information under time pressure, suggest that the ability of the driver to observe the environment efficiently is so critical to the driving task that the driver should be taught a sequential scanning routine as part of driver education.

The driver's scanning technique is a function of his particular experience and, as such, is unspecified here. What can be said is that he has developed a routine to gather information. While driving, he scans his environment and searches for information (signals). He is faced with the problem of having to maintain an appreciation of a dynamically changing environment in which he must continuously predict what will occur in the next instant. In addition to predicting, he must integrate the information he receives to maintain the dynamic appreciation. The more events that are occurring in his environment, the less time he has to attend to any one signal. Several studies $(84,85)$ postulated that the driver has some spare mental capacity while driving. (Spare mental capacity is measured by the ability of a driver to perform a subsidiary, nondriving-related task while driving.)

These studies have demonstrated that in low-attention demand situations, the driver does not completely attend to driving but has some attention capacity left over. As the driving task becomes more demanding in terms of attention, the subjects in these studies were unable to perform any subsidiary tasks, indicating that there is a limit to the driver's attention capacity. This implies that no low primacy signals should be presented in high-signal areas, because the driver's capacity to attend to information sources may be decreased and he may miss needed information.

Signal Detection and Recognition.-The signal detection and recognition discussion is presented, assuming that the signal detected is the only signal present in the environment and that the driver is not under any time pressures.

In any situation, there is a likelihood (86) that the desired signals will appear in conjunction with unwanted signals (noise). This implies that, for a signal to be detected by the driver, the signal-to-noise ratio must be high enough for him to pick out the desired signal and reject the noise or unwanted signal. In the case being considered, it is assumed that the detected signal intensity is sufficiently higher than the noise intensity to allow it to be detected. As the driver is progressing along a road, he can detect a signal that he cannot as yet recognize.

Because the example assumes that the signal detected is the only signal, he can attend solely to it and does not have to time-share (except for the microperformance). Another way of stating this is to say that the detected signal is the only information load (the process of shifting attention is referred to as load-shedding). Except for the fact that a signal has been detected, the driver has not yet received any specific information.

After a finite period of time, the signal is perceived by the driver to be a sign. When he perceives a sign, he can shift his attention to another source (load-shed) without having to read the message. In high-signal areas, loadshedding is an important element of the driving task. When the driver detects a signal that may contain information that he needs, he can shift his attention to other activities while delaying reading the sign until he gets close enough for the sign to be legible.

As he gets closer to the sign, more and more attributes of the sign become visible. For example, the driver may reach the point where shape and color of the sign are recognized. When shape and color coding is employed, the shape of the sign should be familiar and easily identified by all drivers, because quick identification reduces time required for load-shedding and task-sharing.

As in the case of detecting and recognizing the sign, the ability of the driver to read and understand the information on the sign is a function of his a priori knowledge. The message contained on any sign must be able to be read and understood.

Decision Making.-The driver is constantly sampling information from many sources by time-sharing his attention and load-shedding as the situation warrants. This shifting of attention is a function of his scanning routine, the level of performance, the interactions of subtasks, the self-pacing characteristics of the driver, and the external pacing characteristics of the road.

Cumming (1) stated that the self pacing of the driver is analogous to the social-psychological concept of "level of aspiration," because the driver has a self evaluation of what he is able to do and also what he is comfortable doing while driving. This self evaluation is usually slightly above what he is capable of attending to and processing. External pacing of the road refers to the attention demands that the road places on the driver. Problems may arise if the external pacing of the road is either too high (so that he cannot perform adequately) or too low (so that he is bored and does not have enough to attend to and process). When external pacing is too high, the driver can miss signals by not paying attention to them. In other words, improper load-shedding could occur. Under highsignal and time pressures, the driver could have very little time to perceive signals. This leads to the driver not have enough time to make control decisions.

When the attention demands of the road are too low, two serious problems can result. For one, if his self-pacing conceptualization is significantly above the external pacing of the road, the driver may perform unnecessary or dangerous maneuvers such as excessive lane changing or increasing speed to compensate for the low external pacing of the road. The second problem concerns vigilance, where the driver may miss signals.

Zuerscher (87), in reviewing the literature relevant to vigilance behavior, identified attention and expectancy as being two major theoretical formulations (the others being inhibition and arousal). Because both of these concepts are identified as principal factors in this research, the question of vigilance is one that bears examination. Adams (88) defines vigilance as

> for, a descriptive term for the behavior of the watcher Usually these signals occur irregcularly over riclatively long periods of time.

A vigilance study (89) to determine the ability of an operator to detect signals in military monitoring tasks (such as radar monitoring) indicated poor ability over long periods with weak stimuli. The low-traffic, uncomplicated, rural road appears to bear enough resemblance to the military vigilance tasks to be analogous.

Hulbert (14) reviewed the vigilance literature and presented a list of important factors both facilitating and adversely affecting detection performance:

## 1. Factors Facilitating Detection Performance:

a. Knowledge of results.-Information to the monitor indicating that he has or has not detected a signal decreases his error rate.
b. High-signal frequency.-Error rate in the monitoring task is inversely proportional to the frequency of signal presentation.
c. Intersignal regularity.-Error rate decreases when signals are presented at regular intervals.
d. Cross-modulation redundancy.-Use of more than one channel (e.g., auditory and visual) yields a higher detection rate, provided that they present data on the same stimuli.

To the list, the following can be added, after Cumming (16):
e. Prior warning.
f. Arousal.-Arousal by other means such as curves in the road or other relevant information telling the driver how his trip is progressing, etc.
2. Factors Adversely Affecting Detection Rate:
a. Age.-Older drivers cannot maintain vigilant behavior as well as young drivers.
b. Competing tasks.-Competing tasks adversely affect vigilance performance.
c. Noise, vibration, heat.
d. Drugs and alcohol.
e. Fatigue.

The designer must consider, when analyzing any segment of road, that there may be stretches where the attention demand is high, as in urban areas with frequent interchanges and high Annual Average Daily Traffic (AADT), and that there may be areas where the attention demand is low, as in rural areas with infrequent interchanges and low AADT and high Average Trip Length (ATL). He must realize that neither an extremely highnor an extremely low-signal area is desirable, because an extremely high-signal area could lead to improper loadshedding, whereas an extremely low-signal area could lead to a vigilance problem. One way that a designer could facilitate the driver's task is by avoiding the presentation of low primacy information in the high-signal areas and presenting it in the low-signal areas, thereby spreading the peaks and valleys of attention demands and somewhat aiding the vigilance problem.

Returning to the example of a signal being detected and
recognized, the next concept to be considered concerns decision making, and the concept is that of channel capacity. The driver, having searched for, detected, and recognized information, makes control decisions based on the processed information and the a priori knowledge that he has in storage.

Information theorists (19,90) conceptualized information in terms of "bits." In the simplest situation, where, through learning or conditioning, one specific stimulus leads to only one specific response, it can be seen that there is no uncertainty to be resolved and, therefore, the decision of making the specific response to the specific stimulus is said to be a zero-bit decision. From the previous discussion of the microperformance it can be seen that most of the control decisions at this level are zero-bit decisions. Even a zero-bit stimulus-response decision takes some time, the simple reaction time between the recognition of the stimulus and the response made by the driver (56). Cumming (16) cited evidence showing that, for visual stimuli, one simple reaction time is about 0.186 sec . Therefore, a zero-bit decision was shown to take 0.186 sec . That all decisions take some time becomes important in view of the fact that a driver may be timesharing many sources of information and may be under much time pressure in certain situations. As the decisions become more complex, the time taken to make them increases.

Whereas a zero-bit decision leads to only one possible response, the next higher order decision, a 1-bit decision, could lead to one of two equiprobable responses. An example of a 1 -bit decision is where the road divides around an obstruction with a sign indicating pass left or RIGHT. The approaching driver must then resolve the uncertainty of the situation by deciding which way to pass. He is faced with a possibility of two equiprobable responses: to go left or to go right. The way in which the driver resolves the uncertainty depends on the information he receives. If, for example, he sees a stalled car to the right, he can resolve the uncertainty of the situation. In this case, the driver resolves the uncertainty on the basis of his subjective estimation of the situation, relying on his past experience and expectations. If he delays making any response, this may result in his crashing into the obstruction. Ambiguity must be avoided because it creates uncertainty or delays responses.

Assuming that the driver has the one bit of information needed to make the decision, Cumming (16) indicates that the time required to make the decision is equal to the sum of two simple reaction times, because there are two equiprobable responses that the driver could make. Thus, a 1 -bit decision requires 0.316 sec . Similarly, a decision yielding four possible equiprobable responses is said to be a 2-bit decision, and so on, so that an $N$-bit decision can be expressed by the term $2^{N}$ equiprobable responses. As decision complexity increases (i.e., more probable alternatives), the amount of information needed by the driver to resolve the uncertainty increases, and the information challenge is said to have increased. Similarly, as the decisions become more complex, the amount of time needed to make them increases linearly as a function
of the number of bits of information needed to resolve the uncertainty so that a 3 -bit decision requires $3 N+1$ simple reaction times, etc.

As the information challenge increases, a point is reached where the driver is unable to handle and process the amount of information required to resolve the uncertainty of the decision. It is at this point that the driver's channel capacity is said to have been exceeded.

To discuss channel capacity, the concept of a human observer as a transmitter of information (19) has been used. Miller (17) reviewed human information processing in terms of information theory with the human observer likened to a communication channel; he defined the "channel capacity" of the human observer as that "asymptotic value where an increase in the input of quantity of information yields no increase in the transmitted quantity of error-free information." Miller then goes on to present data on unidimensional * stimuli inputs and shows the channel capacity of the human observer to be $7 \pm 2$ equiprobable alternatives or approximately 2.8 bits. Another important point, discussed by Quastler (91), concerning the channel capacity of the human observer, is that if the information challenge becomes very great, the "confusion effect" sets in so that not only is the driver unable to process the heavy information challenge, but he also seems to show a marked decline in the amount of information that he can transmit error-free; in other words, his channel capacity is decreased.

A correlative of decision complexity is decision rate. Driving requires a succession of decisions, so that the rate at which information can be processed becomes important. As the decisions become more complex, the time required to make each decision increases. Therefore, although a series of zero-bit decisions, each requiring 0.187 sec, can be made at the rate of 5.35 per second, and a series of 1-bit decisions, each requiring 0.316 sec , can be made at the rate of 3.16 per second, when a 6 -bit decision

[^10]is reached, with a decision time of 0.972 sec , only one decision can be made per second.

This means that, as time pressure increases, it is simpler for the driver to make a series of uncomplicated decisions as compared with his having to make a few more complex decisions, because a simple decision takes less time, and more simple decisions can be made in any given time period. However, with no time pressures, the converse is true, because a driver can resolve more uncertainty in a more complex decision. (For example, five zero-bit decisions made sequentially resolve five equiprobable responses, whereas one 5 -bit decision made in the same time period can resolve 32 equiprobable responses.)

## Synthesis of Principles

A synthesis of the findings presented in this chapter yields a group of concepts and principles that are applicable to the systematic presentation of needed information for the highway user.

## Relationships of Some Principal Factors

Figure 2 shows the relationship of some of the principal factors for situations that were frequently encountered in the course of the driving task analysis. The principal factors shown are:

1. Levels of performance.
2. Primacy.
3. Attention.
4. Processing capacity.

The subtasks are associated with each level of performance and their related information needs interact with the factors just set forth. To accomplish this, the relationships have been plotted in terms of their temporal interactions.

The abscissa represents time and is nonlinear. The reason for the nonlinearity is the nonequivalence of time from level to level. For example, the tracking task was shown by Cumming (16) to operate at about 2 cps , whereas the driving task analysis found certain macroperformance-


Figure 2. Relationship of principal factors.
associated information needs that had a cycle time equivalent to one cycle per trip. Therefore, the time base provides a qualitative representation of the temporal relationships that may be found in the course of a trip.

The ordinate is identified as urgency that is derived from the factor of primacy. Assuming that the driver is skilled and experienced, the figure represents the case where the objective primacy for the situation and the situation and the subjective primacy of the driver correspond.

The straight line drawn parallel to the abscissa represents a value of urgency called Level of Attention. Its significance lies in the fact that activities represented by portions of the curves falling above this line are considered to be attended to. Portions of the curves falling below this line represent activities that were found either not attended to or carried on without the driver being aware of what he is doing.

A second plot, Processing Capacity, corresponds to the concept of processing capacity discussed previously in "Driver Information Processing Characteristics." The ordinate for this plot is expressed in terms of "spare" or "full," corresponding to Brown's concept of "spare mental capacity" (84). When this plot exceeds the "full" level, the driver is overloaded.

Situation 1 represents the pretrip phase for a first-time trip requiring "formal" trip planning. Throughout the major part of the pretrip time interval, just up to the start of the trip, the macroperformance level is the only level present with a high urgency rating assigned. This is because the pretrip phase is concerned primarily with trip planning and preparation, which are macroperformance activities. Approaching the start of the trip, the following relationships can be seen:

1. The situational performance begins to increase in urgency, indicating the driver's need for information relating to situational performance requirements (e.g., What are traffic conditions? Is it raining?).
2. The situational performance level is followed by the microperformance level, which increases in urgency, indicating the driver's need for information relating to microperformance requirements, primarily of a vehicle operating condition nature (e.g., Is the vehicle in good operating condition? Is the fuel supply adequate?).

As the situational and microperformance levels increase in urgency, the macroperformance level shows a decline so that, at the start of the trip, the three levels of performance are about equal in urgency. Situation 2 represents a situation that may be encountered at the start of a trip. For illustration, it can be assumed that the driver is faced with an immediate decision of whether to go left or right. When he decides, there is a decline in the urgency of the macroperformance level.

The urgency of the situational level increases and peaks with the urgency of the microperformance level following the situational level with a short temporal lag. This lag represents the fact (discussed previously under the heading of "Primacy" in "Description of Driving Task") that the needs of a level of performance lower on the objective
primacy scale intensify everything relating to this need higher up on the primacy scale.

A preliminary system analysis has shown that a driver has to search the environment to determine whether road and traffic conditions are such that he can enter into the traffic stream. When this decision is made, the driver's attention shifts to the microperformance information needs associated with the vehicle control tasks needed to position the vehicle on the road.

Figure 2 shows that the driver's processing capacity is being taxed by the situation described so that it is nearly at the full level. The processing capacity is predicated on the information load and the number of competing information sources. In this instance it is assumed that the driver's capacity is not overloaded. Once the driver has positioned his vehicle on the road, the urgency associated with all the levels of performance is seen to approach and cross the Level of Attention line, showing that the steadystate condition is being approached. Situation 3 is a steady-state condition representative of the driver on course on a "good" road with little traffic or other situations existing. In this case, the macroperformance level is seen as being below the level of attention because the driver is on course, with no decision points or service needs. In such a situation a characteristic shifting of attention between the microperformance level and the situational level is shown, after Cumming (16).

The microperformance shows a short duration rise above the Level of Attention line, following a sinusoidal wave shape, followed by a rise in the situational level as the microperformance level falls below the Level of Attention line. The microperformance wave shape represents the incremental course corrections that the driver makes to maintain position and tracking control, whereas the situational level represents the signal search and detection activities.

In the steady state, with little in the way of external events, this cyclic behavior is characteristic of the driver's scanning routine and internal pacing. Examples of this type of driving can be found on certain rural expressways. As can be seen, the processing capacity of the driver under these conditions is at the "spare" level, indicating that he has reserve capacity and pointing to the fact that a vigilance problem may arise if the duration of this condition is protracted.

Situation 4 shows how a situational performance situation was found to operate. Many examples could be cited as illustrative of this type of driving behavior, such as:

1. Severe alignment change.
2. Obstacle in the road.
3. Lane drop.
4. Lead car stopped.

In any of these situations, the situational needs rise sharply in urgency, followed by a rapid rise in the microperformance level. In the case of severe alignment change, the situational level peak shows that the driver has received the information associated with the alignment change. This is followed by the driver's microperformance vehicle control modifications, which peak in urgency until the
control modification decision is made, the control task is performed, and the adequacy of the action is established. After the adequacy of the response has been established, the curve returns to the steady-state condition.

The processing capacity curve during the sitüational level situation shows a rise toward the "full" level, indicating that the driver's processing capacity is being stressed. Although only one situational performance requirement is shown in the diagram, it can be seen that if another situational performance requirement occurred in close temporal proximity, there would be little "spare mental capacity" remaining, with a distinct risk of overloading the driver.

Situation 5 illustrates a situation where a macroperformance information source, requiring no control actions, is received by the driver. On the driver's receipt of the message, a rapid rise in the macroperformance is shown crossing the Level of Attention line, showing that the sign has sufficient attention-gaining characteristics. The urgency is shown as peaking and then rapidly falling off, showing that the driver has processed the sign message, load-shed, and resumed his steady-state driving pattern.

The processing capacity curve follows the macroperformance curve, showing that the driver's processing capacity is taxed while processing the information from the sign. This curve shows the need for a driver to be able to perceive and process the information challenge of the sign or reject the sign as quickly as possible, so that he will be able to attend to a new information source which, although not diagrammed, could compete for his attention. Under time pressures, this quick rejectability feature of signs and signals is important because it means that the driver's processing capacity will allow for the processing of other information.

Situation 6 represents a situation where information at all levels competes. Such a situation was found to occur at exits or interchanges where a course change is required.

The macroperformance level is the first to show a rapid urgency rise and represents a driver perceiving a needed guide sign which, in accordance with his trip plan, indicatcs a necessary change in course. The time represented by the width of the macroperformance level curve also includes the time that the driver needs to make the decision to exit. The more complex the decision, the longer will be the time needed to make the decision.

Owing to the nature of the primacy scale, the macroperformance level gives rise to an increase in the urgency for the situational performance level. It is noted that the intersection of the situational and macroperformance curves indicates task- and time-sharing as well as competing information needs. The rise in the situational level curve indicates that the driver is attending to such things as traffic conditions and exit geometry. The situational curve in turn gives rise to the microperformance curve indicating that the driver is making the necessary tracking and speed control modifications implied by the course change. Inspection of the curves representing situation 6 indicates that there is a large amount of task-sharing, timesharing, and competing needs in such situations, indicating
that interchanges and entrances and exits present the most complex and critical problems to the designer of an information system.

## Primacy

There are many times and places when information needs compete for the driver's attention. In most instances, the driver is able to time-share efficiently by relying on experience, a priori knowledge, prediction, and expectancy that enables him to load-shed correctly and attend to all sources of information. However, as has been determined by the driving task analysis, and shown in Figure 2, there are situations and circumstances in which the driver is unable to handle the information load because his processing capacity is exceeded. The results of this inability to process all information sources could result in improper load-shedding or missed signals. It was found that the driver attends to information sources that he deems most important. This is the driver's subjective primacy.

The objective primacy generated by the highway elements was shown to follow a scheme in which the microperformance is prime, the situational performance is lower in primacy, and the macroperformance is least important. Concerning the concept of objective primacy, the point must be made that there is a primacy structure that can be applied to a specific location and is applicable to that location only. It is important to note that no single information need discussed in this report is either always present or always unsatisfied. In locations where microperformance needs are either satisfied, or are not applicable, situational needs assume the highest primacy. When situational needs are satisfied or are not applicable, macroperformance needs assume the highest primacy. The designer must analyze the specific location under consideration to derive the primacy structure that is most applicable for that location.

The subjective primacy of the driver should accord with the objective primacy of the situation. Whenever a location is found to have an external pacing beyond the capabilities of the driver, the presentation of needed information must be in agreement with the objective primacy of the location, with avoidance of extraneous signals and secondary needs.

## Spreading

Figure 2 shows that there are times during the driving task when the driver's processing capacity is fully used or overloaded, as well as times when his processing capacity is almost completely unused. In previous sections the points are made that both unused processing capacity and overloaded processing capacity present serious problems.

When the driver has little to do, representative of the condition where the driver's processing capacity is almost completely unused, two possible problems exist. The first problem involves the self-pacing attribute of the driver. Self pacing refers to the fact that drivers seem to prefer to set their pace in accordance with their own subjective concept of what they down do.

In locations where little in the way of events or signals
is occurring (e.g., on rural freeways) the external pacing of the road is said to he very low. When the external pacing of the road is low, drivers have been found to create their own work in order to satisfy their self pacing. Thus, if little is occurring, drivers may execute unnecessary and even dangerous maneuvers to give themselves something to do. A second problem in low-signal areas is that of vigilance, where operators have been found to miss needed signals for no apparent reason. This is an important consideration for the older driver who has been found to be less vigilant than the younger driver.

In high-signal areas, where many signals are competing for the driver's attention, entirely different problems exist. If the driver's processing capacity is overloaded, he may miss signals because he was unable to load-shed properly. He may also be faced with the problem of not having enough time to make a decision, leading to confusion or to decision making on the basis of incomplete information.

One way to avoid the problems caused by too few or by too many signals is by applying the principle of spreading. In applying this principle of spreading a processing capacity profile with peaks (too much information) and valleys (too little information) is determined. The objective primacy of the situation is determined and the less important information needs at the peaks where too much is occurring are transferred to the valleys, thus approaching an even distribution of information presentation and minimizing the problems of the low- and high-signal areas.

## Recoding

Although channel capacity is a fixed value for a particular individual and a particular channel at a particular time, it is possible to increase an individual's apparent channel capacity.

Recoding is a way to organize bits of information into chunks. There is a limit to the amount of information that can be processed in any time period (channel capacity). The limiting factor for recoding information is the driver's span of immediate memory, which is independent of channel capacity (17).

The principle of recoding states that if a complex code can be taught to drivers, elements of this code can then be presented in lieu of the original information.

For example, the specific combination of shape and color of the Interstate shield, combined with the number shown, contains information as to the type of road (i.e., adequate lane width, high-quality surface, and moderate alignment changes), and the type of traffic flow (i.e., high speed and absence of cross traffic). It also contains information as to which specific route it is and, coded into the numerical designation, information as to predominant cardinal direction and whether it is a main-line section, spur, or loop, and even which general geographic area the route traverses. Unfortunately, the last part of this code, the meaning of the Interstate route number, is not known by the majority of drivers.

An important limiting factor in recoding is that the driver must know the code. Thus, if recoding is contemplated, it must be accomplished with the realization that drivers must be taught the code.

Recoding is a powerful technique that should be applied in the design of any information system, with special emphasis in areas where the channel capacity of the driver may be overloaded.

## Redundancy

Redundancy refers to the principle of presenting the same information in several different ways. A stop sign is a good example of the use of redundancy, where the shape of the sign, its color, and the message stop all carry the same information but in different ways.

There are several reasons for applying the principle of redundancy. First, if a signal is missed in one code it can be detected in another (if the message on a stop sign is missed, the shape may be detected).

Another reason for using redundancy is to increase the percentage of drivers able to use the particular information carrier. For example, a guide sign displaying both the local name and the numeric route designation will serve those segments of the population looking for the particular route by one designation and unaware of the other.

A third reason is to avoid the possibility of ambiguity. Any nonredundant message can lead to uncertainty; however, more than one message providing the same basic information can help to reduce both ambiguity and uncertainty.

## Number and Complexity of Decisions

Every time a driver is called on to process information and make a decision or a series of decisions, he is required to make these decisions in a finite amount of time. The gross quantification of decision time as a function of decision complexity is discussed in previous sections. Generally, the more choices involved in each decision, the longer it takes to make each decision. Thus, in a given time period, there is a limit to the number of decisions that can be made. This limit is equal to the sum of the decision times. If five simple (zero-bit) decisions or one complex ( 2.33 bits) decisions can be made in 1 sec , a situation that calls for six zero-bit decisions in 1 sec should not be allowed. Therefore, in circumstances where time pressures exist (complex urban interchanges) the number of decisions should be minimized.

When designing an information system, the designer must evaluate what the time pressures and quantity and complexity of decisions are so as to determine whether the number of decisions are within the processing capability of the driver.

## Expectancy

Expectancies are a function of the driver's experience and a priori knowledge. An important part of driver education and experience is the development of a set of realistic expectancies. McGill (82) points out that there are expectancies held by the population in general that may or may not be related to the driving task. Equating red with danger and green with safety is indicative of this kind of expectancy. It is not the intent of this discussion to con-
sider these population expectancies, except to recognize that they exist and should not be violated. The purpose here is to discuss those expectancies specifically associated with the driving task. In delineating these expectancies, the level of performance scheme is used.

Microperformance Expectancies.-Microperformance expectancies are those associated with the vehicle and its position on the road. That drivers expect their vehicles to respond to their control actions is indicative of expectancy at this level. Once position on the road has been established, the driver relies on inference and prediction to maintain position on the road. It can be seen that anything occurring that is not within the realm of what the driver expects can lead to trouble. For example, if the driver expects the road to go left and it goes right, he could run off the road. Another important road microexpectancy has to do with road surface conditions. Most experienced drivers know what to expect when they encounter an icy or a wet road. When the driver does not know what to expect, the probability that he will lose control of his vehicle is increased. A perusal of the microperformance information need tables (Tables 3 and 4) will assist in determining what expectancies are implied by each information need. Microperformance expectancies operate below the level of consciousness.

Situational Performance Expectancies.-The importance of expectancies is perhaps greatest at the situational level. There are two subdivisions of expectancies that are discussed in this section: road situational, and traffic situational.

Road-Situational Expectancies.-Alignment changes provide examples of how expectancies at this level can be structured. Drivers expect some alignment changes on all roads and, depending on their experience on the particular type of road, expect to make speed and tracking corrections. However, they may not expect severe alignment changes, especially on interstate-type roads, and must, therefore, be warned prior to the change. Warning signs must be used to structure driver expectancies. Few drivers expect lane drops and other changes in cross section. Therefore, warnings of these changes are necessary.

Another class of expectancies involves interchange configurations, such as whether exits are on the left or right. Because left exits and entrances are seldom encountered, they are counter to driver expectancies. Presently, very little information on type and configuration of interchange is presented to the driver. His expectancies are rarely structured except by a priori knowledge. Because there is much variation in configuration even between consecutive interchanges, expectancy must be structured either before or during the trip.

Unusual conditions, by definition, do not meet the expectancy of the driver. This includes such things as construction or emergency lane closures. Prior warning must be provided for any unusual conditions.

Traffic-Situational Expectancies.-Shore (80) discussed differences in traffic-situational expectancies from locality
to locality. The main point of his thesis is that people from different localities have built up expectancies that, although applicable to their area, fail in other areas. It may be inferred from his work that much in the way of traffic-situational expectancies must be looked at in terms of location.

If a car's left-turn signal is on, the car is expected to turn left. Similarly, when approaching a green light, the driver expects cross traffic to stop. Intervehicular signaling is indicative of expectancy structuring at this level. Brake lights, turn signals, and small wisps of smoke emanating from a tailpipe are bits of information that tell the driver what to expect. Expectancies can be falsely structured at the traffic-situational level. When one observes the tail light of a lead car go on, this may structure expectancy that the lead car will slow down. However, it is possible that the light is from the lighting system being turned on, not the brake pedal being depressed.

Macroperformance Expectancies.-The final category of expectancies involves direction finding and service needs. An important aspect of this phase of expectancies is that they are most amenable to structuring because so much of the macroperformance is involved in pretrip preparation. The driver expects to find in-trip cues that correspond to his trip plan. He expects to find signs telling him where he is and which way he is going. He also expects to find information telling him where services are located and how to get there. At the macroperformance level of driving, the greatest potential exists for structuring expectancies (through maps) and then satisfying these expectancies (through signs).

## SATISFACTION OF INFORMATION NEEDS

## Aiding Concepts

Aiding, as used throughout this report, is a concept that includes all physical means whereby the reception and processing of information by the highway user is assisted. It includes the implicit and explicit presentation of information, the assisting of the signal search and detection task, the structuring of expectancy, and all other means of enhancing message comprehension. It should be clearly understood that this use goes beyond the traditional meaning of the word as used in human factors or information engineering. Any sensory input can be analyzed with respect to its influence on the information reception and processing abilities, and any such input may show positive or negative affects-that is, it may enhance (aid) or detract from (inhibit) the information to be received and processed. This has special importance for all inputs to the visual channel because highway information systems rely heavily on the visual display of information.

Aiding is considered here, and in subsequent portions of this report, as falling into three basic categories: informal, quasi-formal, and formal. These are not discrete categories, but rather can be considered as arranged as a continuous scale. This scale, in terms of the degree of information giving intent, increases from informal to formal aiding.

## Informal Aiding

Informal aiding, quantitatively the largest, contains all information gathered from sources in whose inception information giving was not a consideration. This includes all unaltered natural features and those man-made features constructed with no regard to their information potential.

It must be realized that this use of the term "informal aiding" represents an ad hoc definition, adopted for the purposes of this report, and overlaps considerably the area commonly considered as "unaided." The necessity of considering the possibility of manipulating all information sources, and the introduction of the concept of inhibiting, which may be considered the negative portion of the continuous aiding scale, make this departure from standard nomenclature necessary.

In terms of previously established categories, informal aiding includes a great portion of the information at the microperformance level, especially those items concerning the vehicle's condition and operation that are perceived on the auditory, kinesthetic, tactile, and olfactory channels. It includes road microsituational information received by, or inferred from, the visual impact of the road ahead, and that part of traffic situational information that is not handled by formal visual or auditory intervehicular communications. Also included is macroperformance information gleaned from the recognition of topography, cultivation and land-use patterns, and landmarks, natural or man-made. Finally, it includes a great deal of infurination classified as ARI (Advisory, Restrictive, or Inhibitory), notably those items concerning prevailing climatological conditions.

Although informal aiding is defined as emanating from sources in which information giving is not a consideration, this is not meant to imply that this type of aiding cannot be manipulated so as to enhance its positive aspects and reduce its negative aspects. Such manipulation may be of such an extent as to transfer this type of aiding into the quasi-formal or formal categories.

Examples of such manipulation include the selective clearing of existing vegetation to emphasize road alignment or to clear lines of sight, camouflage, or conspicious treatment, as required, of structures visible from the highway -or even an emphasis on high-visibility colors for automobiles.

## Quasi-Formal Aiding

The category of quasi-formal aiding can be divided into two main parts. The first of these comprises those aspects of the over-all highway system characterized by the fact that information giving is not a prime consideration in their initiation, design, or implementation but is, or should be, a subsidiary consideration important enough to dictate alternatives or changes in design.

The category of quasi-formal aiding is one in which the driver receives, or should receive, a great deal of information at all levels of performance. Consideration, in the design stage, of the information-giving capacity of manmade objects and natural features, which are nominally informal aids, transfers these entities into the quasi-aiding
category. This transfer minimizes the potential of inhibiting the reception and processing of information.

The second part of this category contains devices that are information centered but where the information given is not necessarily determined or structured with the needs of the highway user being predominant. Commercial radio and roadside advertising are prime examples.

The category of quasi-formal aiding, in which the driver receives a great deal of information at all levels of performance, is the one in which manipulation is most feasible, most promising, and most necessary. This is especially the case when quasi-formal aids, or informal aids, are negative in effect to the extent of giving false or misleading information or structuring false expectancies.

A good example of this, not only in its applicability but also in the frequency with which it is encountered, is represented by the case of pavement joints. The standard paving machine will pave, at one time, a strip of concrete 12 ft wide. The fact that this is the standard lane width is no coincidence; one was developed to conform to the other. The joint between adjacent pavement slabs, on multilane highways, is therefore perceived by the driver, especially on relatively new pavement and with the use of bituminous joint fillers, as a distinct dark line parallel to his direction of travel. It is a considerable aid, in the absence of or supplementing more formal aiding such as painted lane lines, in supplying the information the driver needs to define the limits in which he performs the tracking task.

However, the total pavement width is not always an even multiple of 12 ft . In gores, in transition sections, and at some other locations the edge-to-edge dimension of the total pavement may be any numerical value larger than a single lane width. In those cases, the pavement joint no longer unequivocally coincides with the limits of the individual lanes, nor is it, necessarily, parallel to the direction of travel. The danger of presenting misleading information, and structuring false expectancies, is therefore extremely large, and the responsible engineer must be careful to try to minimize this side effect.

This can be done by locating construction joints, using their information-giving potential as the prime determinant, or by leaving them in their optimum location, for reasons of economy of construction and maintenance, and covering them with a thin layer of asphaltic concrete or sheet asphalt overlay.

The possible examples of quasi-formal aiding encompass practically the whole gamut of highway location, design, construction, and maintenance, as well as most aspects of vehicle design. Landscaping, the color of protective paint for structures, the selection of bridge types, and the silhouette of vehicles are just some of the few that may be cited.

The second subcategory of quasi-formal aiding, as defined previously, can be considered as a formal aiding system outside the highway information system but impinging thereon. It is therefore characterized by the fact that it is optimized by the application of criteria not necessarily reflecting the information needs of the motorist or the human factor principles underlying the reception
and use of this information. Manipulating this category can range from outright abolition * to regulation of one degree or another. It should be realized that this category too can give false or misleading information, such as horn and siren sounds sometimes used in radio commercials.

## Formal Aiding

Formal aiding includes signs, signals, markings, and other traffic-control devices whose purpose it is "to regulate, warn, or guide" traffic (92). It also includes all formal display of information within the vehicle and formal means of intervehicular signaling. Finally, it includes news transmitted via public channels, by the highway authorities, and intended for the actual or potential highway user. Because the greatest proportion of the subsequent portions, of this report deals with the capabilities and specific arrangement of formal aiding devices, they are not considered at greater length here.

The preceding discussion, including the examples used, concentrates on aiding concepts as applied to the transmission of information to the driver while he is engaged in the act of driving. The concept of aiding, of course, also applies to the pretrip phase where formal aiding becomes predominant, although some quasi-formal aids are also used.

## Basic System Requirements

An information system for the highway user, where information system is defined as the sum total of all elements that, individually and collectively, determine the type (what), the method (how), and the time (where or when) of presenting information to the highway user must be in accord with the following principles:

1. The information system is a subsystem of the highway system. Relevant elements of both must be identified to determine where tradeoffs are required.
2. The proposed information system should be as compatible as possible with the existing highway system and information subsystem.
3. Because implementation of any changes will be gradual, all elements of the proposed system must coexist with the elements of the existing system.
4. The driver will continue as the main controlling element.
5. The driver's ability to perform adequately (safely, comfortably, efficiently, and conveniently) is crucial to the performance of the highway system.
6. The driver must have all the information that he needs. In human factors terminology, any information system must be user-oriented.
7. The user must be described in terms of his requisite tasks.
8. The information system must use the driver's abilities and also recognize his limitations.
9. The driving population is heterogenous, and there is much variability in driver attributes. Thus, the informa-

[^11]tion system must accommodate worst-case drivers so that the maximum number of drivers will be serviced.
10. The system must accommodate drivers at any time of the day under any conditions of ambient lighting, weather, or other factors.
11. Because average trip lengths are increasing and political boundaries have little significance, the information system should be adopted uniformly to reduce confusion.
12. The implementation of any new or revised information system will require a method of informing the driver of its details and use. One way of ensuring that an information system will be compatible and easily used by drivers is to make the system as "self-learning" as possible. This self-learning concept does not imply that some other means of informing the public is not essential.
13. The relevant elements in the highway system must be evaluated to determine whether these elements can be optimized to minimize the need for road microsituational information.
14. The information system should be as forgiving as possible so that catastrophic failures need not occur as a result of a missed signal or sign, etc.
15. The information system must be designed so that its failure does not make the highway system unusable.
16. Because the implementation of any information system will require the allocation of scarce resources, it must be possible within the availability of these resources and must show a benefit-cost ratio that will justify this allocation.

These elements can be reduced to six major points that can be considered the basic requirements of the highway information system:

1. User-centered.
2. Applicable to existing highway system.
3. Usable by all drivers at all times.
4. Fail-safe.
5. Compatible and evolutionary.
6. Economically feasible.

All elements and interfaces of the system must be evaluated with respect to these postulates, and, in cases where two or more of these postulates imply conflicting requirements, a minimax solution must be found.

Subsequent sections and Appendix $H$ of this report present a review procedure designed to assure that these requirements are met in all information systems.

The resulting system will be user-centered because the procedure was developed on the basis of the human factors principles previously derived. It will serve all the drivers all the time within the limits of technical and economic feasibility.

The resulting system will be compatible and evolutionary and applicable to the existing highway system because it places primary reliance on the visual reception of information transmitted by fixed signs and markings. It, therefore, will represent no major technological change from the existing system, require no extensive alterations to and instrumentation of existing highways, and require only a gradual adjustment, of degree rather than of kind, on the
part of the driver. If the visual channel, where formal aiding techniques only supplement the information received via informal and quasi-formal techniques using the principle of redundancy, is relied on, and alternative means of transmission are used, the fail-safe character of the system will be maximized.

It is recognized that, within these limits, no system can possibly accommodate every driver.* Because any component not accommodated by a system represents a threat to that system, it is necessary to correlate the maximum ability of the information system to transmit information with the minimum ability of the design worst-case driver to receive it. Three possible alternatives to accomplish this correlation are suggested:

1. Restrict the driving population by requiring a minimum level of motor skills, cognitive and perceptive abilities (especially visual acuity), physical condition, and psychological and social attitudes. Apart from the practical difficulties of specifying these levels and determining adherence thereto on an individual basis, ** any measure that would result in a radical reduction in the number of persons allowed to drive is impossible of implementation in an automobile-oriented society unless it is preceded by the establishment of equivalent, alternative methods of transportation.
2. Issue restricted licenses, valid for certain classes of highways only, thereby matching the abilities of the driver to the expected worst demand of the driving task.
3. Require mandatory alternative means for receiving information for those drivers who cannot meet minimum standards. An example of this would be mandatory auditory or externally actuated in-vehicle displays for drivers with visual acuity of less than 20/40.

## Application of Principal Factors

This section describes the application of the principal factors previously derived to the satisfaction of driver information needs. The proposed systematic presentation of information embodies the following main features.

## Primacy

Driver information needs are to be satisfied in accordance with the objective primacy of the highway system. Because of the manner in which the driving task is performed and the differences in driver behavior at each level of performance, the form of information presentation at each level will differ.

Microperformance.-Because microperformance information is highest on the primacy scale, it will be presented before situational and macroperformance information when competing needs exist. It is suggested that the information providing potential of the vehicle subsystem be optimized by appropriate design.

[^12]It is suggested that much improvement can be made in the vehicle in terms of information display. Displays relative to vehicle operating condition and handling characteristics, such as air-pressure gauges and brake fluid level displays, are indicative of high primacy information that could be presented.

Two means are recommended for satisfying road microsituational performance information needs. The first is to provide continuous adequate marking and delineations so that the driver can determine immediately his lateral and longitudinal position on the road. The use of some means of telling the driver when he is running off the road, or inadvertently changing lanes, is also recommended. One means of accomplishing this warning is by the use of raised lane markers. The second means is by minimizing these needs by design. Avoidance of severe alignment changes, poor road surfaces, and difficult grade changes minimize the driver's need for road-microsituational information.

Situational Performance.-Although the information needs associated with the situational level of performance are lower on the primacy scale than the microperformance, the importance of satisfying them adequately should not be understated. Once microperformance information needs are satisfied, situational performance needs have highest primacy.

The driver is required to rely on his capability for estimation, prediction, and judgment to perform adequately at the situational performance level. In high-density traffic situations, due to the need for more complex decisions, there is a higher probability that the driver will make a mistake in estimation, prediction, or judgment. Because errors at this level of performance can, and usually do, have catastrophic results, it is recommended that a maximum application of formal aiding techniques be made in this area.

Intervehicular communication techniques should also be considered in great detail. Such devices as proximity detectors, and go, no-go passing displays are needed to aid the driver. (Both of these devices are currently under active investigation under a number of Department of Transportation R\&D contracts. This area is explored further in Appendix F.) In addition, the time pressures should be relaxed by spreading to take much of the peak loading off the driver.

Macroperformance. - Macroperformance information needs are lowest on the primacy scale, and are most amenable to delay. There is no way to satisfy the macroperformance needs for all drivers without considering the importance of the pretrip a priori knowledge requirements. A great portion of the macroperformance information needs can and should be satisfied before the driver starts driving. Given adequate trip planning, all that is needed in the way of on-line directional macroperformance information presentation is information that relates the driver's trip plan to what he receives in transit-that is, telling him where he is and which way he is going.

## Processing Limitations

The systematic presentation of information needed by the driver considers the processing channel limitations of the
driver. The driver should not be overloaded either in terms of his attention-paying and load-shedding ability or his information-processing channel capacity. The attentionoverloading problem is minimized by using the factors discussed pieviously, and by spreading.

## Spreading

To minimize the interrelated problems of overloading and vigilance, the systematic presentation of information should make extensive use of the spreading concept. There should be no stretch of road where the external pacing is either too low or too high. Macroperformance information is to be spread out in time and distance with only essential macroperformance information presented in high-signal areas.

## Expectancies

Maximum use is to be made of driver expectancies in the system. Both driver and population expectancies should be structured by reeducation and mapping, and not violated in that the driver will be warned in advance when the unexpected may occur.

## Summary

The basic tenets for the systematic presentation of information needed by the driver are: *

1. First things first-primacy.
2. Do not overload-processing channel limitations.
3. Do it before he gets on the road-a priori knowledge.
4. Keep them busy-spreading.
5. Do not surprise them-expectancy.

## Conceptual Development of Application Procedure

The empirical and analytical findings reported on in prior sections of this report yielded a conceptual framework of the driving task. This conceptualization takes into account both the psycho-motor and cognitive aspects of the driver as controller, and the interfaces of the driver with the other elements of the highway system.

On the basis of this conceptualization, a theoretical method was developed for the analysis of an information system. This method was derived from the general framework of information requirements and transmission techniques and depended, for implementation, on a point by point detailed analysis of the highway.

In the second phase of this project it was intended to apply this method to a section of existing highway. Site selection criteria were developed and an appropriate site was selected.** Data were collected and analyzed and the original analysis method was revised to conform to the actual demands of this task.

[^13]
## Data Collection and Analyses

Data Requirements.-To develop data collection and analysis methods the data requirements were determined first.

Information Needs.-A basic requirement was to collect data that would permit the determination of driver information needs for an existing section of highway. A "typical" highway section, suitable for the empirical data collection activities, was selected. On selection of the site, a preliminary human factors review of its characteristics was made and an initial categorization of information needs was developed. This preliminary review resulted in the decision to collect the following data:

1. Information Needs Relative to the Over-all Site: Data were required to determine and identify potential information needs relative to the task of negotiating the over-all site. Thus, data regarding macroperformance aspects of the site, such as potential origins, destinations, trip plans, service needs, and alternate routes would be collected.
2. Information Needs Relative to Main-line Travel: Data to determine and specify the vehicle control subtasks for the main line of travel were required. This entailed a determination of the microperformance and situational performance subtasks that the driver would be called on to perform along the site. In the course of this determination, "problem" or "special problem" locations could be identified, and the information needs generated by these locations could be determined.
3. Information Needs Relative to Off-line Travel: Data collection of off-line features of the highway section was determined to be desirable. This entailed a determination of the information needs generated off the traveled way as well as the information needs generated by the off-line (interchange) features of the site.

Identification and Specification of the Level of Performance Associated with Each Need.-In order to apply the hierarchical conceptualization of the driving task to the site, an important output of the data collection and analysis was the formulation of an objective primacy scale structuring the subtasks and associated information needs. To accomplish this, the level of performance associated with each information need was identified and specified.

Determination of Available Information at the Site.At any location on the site, it was necessary to determine whether, how, and what information was available to the driver. This enabled project personnel to determine if, and to what extent, information needs were presently satisfied.

Specification of Location.-The location of subtask and information need occurrence and/or information presentation is a central factor in the application of an "Information Design" and "Application" procedure. Therefore, a means of localizing and specifying the occurrence and/or presentation of information was critical to the data collection requirements.

Determination of Temporal and Spatial Relationships.A means for determining the occurrence of information needs and/or the presentation of information, in terms of location and time exposure, was required. Because the
initial finding of the study indicated that subtasks overlap and cluster in the course of the driving task, a way of determining these relationships in terms of time and distance was required.

Identification of Areas of Potential Driver Overload or Confusion and Other Information System Deficiencies.A final data requirement was that a means be devised to identify, either directly or indirectly, areas along the site where potential driver overload, or confusion and other information system deficiencies occur.

Design of a Data Collection and Analysis Method.The basic methodology for data collection and analysis used to develop the findings reported on previously in this report was a task analysis. Data were collected and analyzed in terms of control actions, information needed and/or received, and decisions required. This analytic procedure is called an IDA (Information, Decision, Action) analysis.

The data collection method used in the initial phase of this study was one in which drivers verbally described information, decision, and action observations while driving. Although suitable for collecting generalized data, this method was not suitable for specific, location-fixed data collection. This method is not precise or sensitive enough to identify and locate all events and subtasks when many diverse sources of information are competing.

In addition, the recording method has too narrow a bandwidth to describe fully all relevant system parameters associated with the occurrence of each information need.

Because this method could not satisfy the data requirements completely, an extension was required. A filmed recording of the test site, taken from a vehicle being driven through the site and synchronized with the verbal record, was the data collection method used.*

## Results of Analysis

The following discussion is presented to provide examples of information systems deficiencies, rather than to criticize the specific test site. The assumption is made that the site selected is "typical" of existing Interstate and Interstatetype highways, and that the results of the analysis can be generalized to other, similar highways.

Thus, although the results presented are directed toward problems associated with the site, this is not to imply that the highways and associated highway information systems analyzed were in any way inferior to present highways and highway information systems.

The analysis showed that there were instances where the system is not providing the driver with proper information to perform the driving task safely and efficiently. Among the reasons for deficiencies found are:

1. The needed information is not displayed.
2. The information displayed is inadequate or incomplete.
3. The information displayed is erroneous.
4. The information displayed is ambiguous or confusing.

[^14]5. The information displayed is not in the form that the driver can best use it.
6. The information is not displayed in the optimum location; the driver does not have sufficient time to perceive and act on the information.
7. Too much information is being displayed to the driver at a specific location (i.e., the attention demands and/or the information challenge are beyond the processing capabilities of the driver). The "important" information is not emphasized and may be missed or perceived in error due to improper load-shedding and/or exceeded channel capacity.
8. Transmission of the information is inhibited due to physical, climatological, or ambient lighting factors.

Each of these deficiencies is discussed, using the findings of the analysis as examples. Although the foregoing factors are discussed separately, it should be noted that these deficiencies can, and did, occur in combination, thus complicating the design problem.

In the discussion of examples of deficiencies in existing information systems, many examples are cited from data collected on US 70, particularly in terms of microperformance and situational performance associated information. This resulted from several factors that have important ramifications for the development of an information system review procedure.

I-85, being a modern Interstate highway, dnes not present the driver with the high microperformance and situational performance driving task loading and difficulty that US 70, an older, rural arterial road, does. This is true of virtually every microperformance and situational performance subtask of the driving task, in terms of both information processing and vehicular control.

Starting with the most elementary aspects of the microperformance and situational performance subtasks-that is, vehicle handling and tracking-it was found that the older, rural arterial road presents considerably more task difficulty and task loading. This was due to poorer road surface, generally poorer alignment, and narrower lanes and lack of shoulder definition.

With regard to the situational performance subtasks, the same problems of increased task difficulty and high subtask loading were also prevalent. Not only were there more varieties of situations, such as "construction," "obstacles" in the road, "at-grade" intersections, lack of medians, and no passing zones, but there were areas of extremely high signal density and subtask interaction that can present the driver with processing overload and increased error probability. In addition, it was found that the older road, as typified by US 70, had a high frequency of blind spots and restricted sight lines.

The modern Interstate, in contrast, was characterized by its lack of microperformance and situational performance demands. Although the Interstate highway did have locations where there were high microperformance and situational performance demands these were few and far between, and not nearly as extreme as those on the rural arterial road.

Thus, it was seen that the nature of the road predicates,
to a large extent, the emphasis that must be given to the associated information subsystem as well as the nature of the information displayed.

In the case of the rural arterial, emphasis must be placed on aiding the microperformance and situational perform ance aspects of the driving task.

Because the Interstate route does not present as many vehicular control challenges to the driver, the reverse is true. More of the available information carrier capacity can be used to provide macroperformance information to the driver and thus make his task more comfortable and convenient. Because less of his driving task is taken up with attending to microperformance and situational performance subtasks, he can attend to directional information and make more complex route-following decisions than the driver on the older road can. The driver on the Interstate is able to attend to and process more timeconsuming verbal information owing to his lessened task loading on higher primacy subtasks.

Deficiencies in highway information systems imply deficiencies in the display of information by means of formal information carriers. Throughout the ensuing discussions, this point is emphasized, and deficiencies in the existing information system are discussed in terms of information displayed via markings and signs.

The discussions are limited to cover information that is amenable to display and aiding by marking and sign channels. In effect, this excludes information from the vehicle itself and from intervehicle communications channels.

When the need for formal aiding was determined, consideration was given to the availability of unaided and quasi-aided information display. Deficiencies in information systems were therefore based on a need to display information that was otherwise inadequate or unavailable to the driver.

Non-Display of Needed Information.-One obvious deficiency noted was the absence of the display of needed information, either aided or unaided.

The majority of cases of non-display of needed information were associated with macroperformance aspects of the driving task (i.e., directional and service information needs). However, there were also some cases of nondisplay of microperformance and situational performance information. Examples cited for non-display of needed information are limited to those cases where no needed information was displayed.

Thus, the criterion that was applied in determining non-display of information was that the needed information was totally unavailable, at any time and from any in-trip source.

There were relatively few instances of total nondisplay of microperformance and situational performance information needs. This was due largely to the fact that the roads were marked and signed in accordance with the applicable signing manuals.

Those microperformance and situational performance information needs, amenable to marking and signing channel display, were therefore by and large incorporated
into the existing information system for the road, even if they were not completely satisfied thereby.

This was found to be the case in most main-line steadystate areas, where the treatments contained in the manual were found to be adequale in satisfying microperformance and situational performance information needs. Where deficiencies were found, they almost invariably were associated with special features. These areas are locations on the road where unexpected events, extremes in road geometrics, high task loading, high signal density, and similar occurrences exist.

An example of non-display of needed situational performance information that was found on US 70 occurred in an area about 2 miles from the beginning of the data collection test run. The area was one where houses were set back from the roadway and were obscured by dense trees. The sight lines in this particular area were such that it was impossible to perceive many at-grade driveways. Several of these blind driveways were further obscured due to the horizontal alignment of the road (i.e., they occurred immediately after sharp curves).

It was interesting to note that no introspective mention of those potentially serious safety hazards was ever made. It took a close, frame-by-frame analysis of the film to determine their existence. It can be concluded that a driver, unfamiliar with this particular route and thus unaware of the existence of these blind driveways, might not be able to perceive and respond to traffic leaving these driveways.

On I-85, examples of non-display of situational performance information were found in several areas off the traveled way, where off-the-road hazards were not perceivable. This was particularly true of culverts that were not protected by guardrails, and were not visible to the driver.

Whereas total non-display of microperformance and situational performance information is infrequently encountered, total non-display of macroperformance information is commonplace. Examples range from unidentified crossroads, encountered on US 70, to guide signs on I-85 that did not identify the full spectrum of potential routes and destinations served by a particular interchange.

Whereas the former example is one that can be readily rectified, the latter examples are ones where no easy solutions are available.

Guide signs, as currently used, cannot possibly satisfy every macroperformance information need for every driver. Thus, there is a present built-in deficiency in the information system design in that there will always be non-display of macroperformance information to some segment of the population.

Inadequate or Incomplete Information Display.-A second class of information system deficiency is where the information displayed to the driver, although readily perceivable, is, to some extent, inadequate or deficient.

This category consists of two subcategories: (1) where there is no formal information display and the unaided information is inadequate or deficient, and (2) where there is formal aiding and the message content of the formally aided information is inadequate or otherwise deficient.

The former is a major reason for formal aiding. That is, with the exception of certain administrative and legally required signing, a primary reason for providing the driver with a formal system of markings and signing is the inadequacy of available unaided information.

It was noted more often on US 70 than on I-85, for reasons previously cited. In several instances, advance warnings of horizontal alignment changes were not present, although they were required, owing to the nature of the road.

An example of inadequate non-aided information display was found on I-85 approaching the US 70 left exit sequence. A left exit is unexpected, so that the very existence of this special feature should indicate the need for some advance warning to the driver. However, such was not the case, and the unaided perception of the situation was not adequate to allow for a safe control maneuver. An advanced warning of this sequence is clearly required but is not present. As is shown, this particular location had other problems associated with it, making the need for advanced warning even more critical.

This deficiency is most apparent at special feature areas, thus pointing to the need to identify and categorize special feature areas on a particular highway segment. This is particularly true of microperformance and situational performance needs. With respect to macroperformance needs, although they do not appear throughout the course of the driving task, they tend to cluster at interchanges. Thius, a detailed analysis and categorization of interchanges is necessary in order to apply a highway information system properly.

The second subcategory of inadequate or incomplete information display involves cases where formal information is displayed. This takes into account information that, owing to inadequate message content, is not sufficient to serve as the basis for adequate control decisions. That is, the formal sign message does not convey to the driver enough information to satisfy his needs.

An example of this type of deficiency occurred in service signing on the Interstate route. In several locations, signs indicated gas, food, and lodging for the exits. However, on taking the exit, it was not apparent how to proceed at the ramp terminus. This was particularly true when the driver could not see the service from the main line of the road. Furthermore, once a driver took an exit, it was not apparent how he was to retrace his steps to return to the main line. In some instances, it was not possible for him to do so. While driving the route at night, it was found that some of the service stations were not open, and thus the gas signs represented incorrect and misleading information.

Erroneous Information Display.-Although the situation was infrequently encountered in the course of the analysis, there were several instances where displayed information was erroneous. An example of erroneous information display was noted in a temporary lane closed ahead sign on US 70, where the lane was not closed.

Ambiguous or Confusing Information Display.-A common deficiency noted in existing highway information
systems is the display of ambiguous or confusing information.

This category manifested itself throughout the entire spectrum of information display, from the microperformance and situational performance information displayed via the markings and delineation channel through the macroperformance information displayed via the guide sign channel.

In the case of microperformance and situational performance display, a common source of ambiguity was found in the many examples of "path confusion" encountered. Path confusion exists when the driver is unable readily to identify the proper path to remain on the main line of the road or to take an exit.

Several cases of ambiguous or confusing information display were found on US 70. For example, a warning sign for a curve was placed directly in front of an intersection that also curved in the direction of the arrow on the advanced warning sign. In this case, it was difficult to tell which was the continuing main line of the road and which was the intersecting road.

Owing to the location of the sign, a driver might mistakenly take the warning sign to indicate a gross change in direction of the main-line road, and, by following the sign, take the incorrect path.

On I-85, the instances of path confusion were found primarily at exits and entrances. These occurred in three ways: (1) due to confusion hetween markings and pavement joints, (2) due to apparent lane additions or lane drops, or (3) due to confusing interchange geometrics.

In the case of confusion between markings and pavement joints, the problem was most apparent at the beginning of deceleration lanes where no lane markings were present. In several instances, when exits were on curves, the pavement joints did not follow the alignment of the road, and led to confusion as to the proper exit lane.

Confusion due to apparent lane additions and lane drops occurred in many instances on I-85. The left exit for the To US 70 interchange had a very long "deceleration" lane that, for all intents and purposes, functioned as a change in cross section and appeared as a lane addition followed by a lane drop. Another example of this type of "path confusion" area was found at the Durham city limits where US 70 joined I-85. This particular interchange is in fact the beginning of a long weaving section, although this is not obvious to a driver on I-85. To the main-line driver, there appeared to be a lane addition. Because of the alignment of the road, it could not be perceived that this lane was, in fact, dropped at the next exit.

In analyzing the film of the road it was seen that the driver had incorrectly changed lanes into what appeared to be the right lane of I- 85 and had to merge back onto I-85 to avoid taking the subsequent and not-wanted exit.

The final class of "path confusion" noted was at "unusual" exits and entrances where it was not apparent which was the main line of I-85.

Two major problem areas were at tangential off-ramps, a relatively frequent occurrence on I-85, and at major bifurcations. With regard to the case of major bifurcations, the most prominent area of path confusion noted
was the US 70, I-85 bifurcation at the east end of the test run. Here, the main line of I-85 went left and the continuation of US 70 went straight ahead, so that a driver in the right lane, wishing to remain on I-85, had to weave across three lanes to remain on I-85. The task of remaining on I-85 was a difficult maneuver and one that was not at all obvious, even though signing had been provided.

Although the majority of ambiguous or confusing information display was associated with microperformance and situational performance information, there were instances where ambiguous or confusing macroperformance information was displayed.

Such an example, found on I-85, occurred in the area of the Gregson Street exit. The advanced warning guide sign read US 501 north-ROXboro, gregson street, which would lead a driver to believe that "US 501 NorthRoxboro" would be the first exit encountered. When the exit itself was passed, it was found that the exit was for Gregson Street and that the "US 501 North-Roxboro" exit was the exit just past the Gregson Street exit. This represents an instance of an ambiguous sign message as it deviates from the usual manner of advance warning, which is to place the first exit as the first line of the sign. In addition, there was no way of knowing whether the advance was for one or more exits.

Displayed Information is not in the Best Form for Reception.-One of information display principles, the importance of which was underlined by this research, is that needed information should be displayed in the form best suited for reception and use by the driver. This principle involves several interrelated factors, including the nature of the information to be displayed, the message content, the sensory channel used in the reception, the reception characteristics of the user, and the physical characteristics of the information carrier.

Two aspects of display form are involved: (1) suitability of the display in terms of type, and (2) suitability of the display in terms of reception by the driver.

In the first case, such aspects of display type as use of verbal versus symbolic or diagrammatic display, use of coded information, and need and use of redundancy are involved.

To analyze a highway information system for deficiencies with respect to display type a rational basis for determining the suitability of a particular information display mode must be developed. However, owing to the complexities of the problem and the many diverse factors involved, clear-cut and readily applicable criteria for display form suitability are not presently available. Further research is required to develop such criteria.

Therefore, it was deemed necessary to consider information display form in terms of broad, general principles that could be applied to existing situations within the framework of existing information display techniques.

At the beginning of this section the point is made that the type of road (e.g., Interstate, arterial) and its associated task-loading and complexity is an important determining factor with respect to information display form. That is, the microperformance and situational perform-
ance subtask difficulty of non-Interstate roads requires that information relative to such things as alignment and obstacle avoidance be presented in as simple a manner as possible. This enables the driver to "take in at a glance" needed path main-line information and thereby attend to other sources of information (e.g., traffic avoidance). This, in turn, suggests that simple, nonverbal symbolic display is the best form for this type of situation.

The type of information display must be evaluated on the basis of many factors, including the type of road, the nature of the traffic stream, and the signal density in a particular area.

This represents only a portion of the factors that must be considered regarding information display type. The human factors subsumed by the various needs of information display must also be considered. For example, any system that employs symbology, graphics, and coding must ensure that knowledge of these symbols or coding systems are part of the a priori knowledge of the user. A case in point is the Interstate coding system for route numbers which, although it is based on a logical coding system, is not known by most drivers.

In evaluating a highway information system, it must be assumed that those codes and symbols explained in the various "Rules of the Road" pamphlets and knowledge of which is required for driver licensing represent the level of user a priori knowledge. Any deviation from these must therefore be considered as a potential deficiency in an information system.

On the basis of the foregoing discussion, the following are examples of information form deficiencies noted in the course of the analysis. As would be expected, the majority of these examples were found on US 70.

An example of the use of a verbal message where a symbolic display may have been more appropriate was seen on US 70 in a dense signal area, characteristic of US 70 throughout the study section. The particular sign read divided intersection ahead, 45. mph. What actually occurred was a change from a two-lane undivided to a four-lane divided section. Not only was the verbal message confusing and incorrect, but the lane additions were not indicated. It would seem that the use of a symbolic display showing the lane additions on one sign, supplemented by another sign indicating the change in speed limit might have been more readily used by the driver.

Another example occurred at an unprotected at-grade railroad crossing on US 70. In this case, the treatment described in manuals for such crossings was not fully adhered to, and the only indication of the potentially hazardous situation was a small railroad crossing sign. Because this crossing is a relatively active one, and because it occurs in a relatively poor visibility area, it would be better handled with a full treatment, including some redundancy, as for example a bell to warn of an approaching train.

A lack of consistancy as to guide sign configurations throughout the entire US 70 section was noted. In some cases, the guide signs were in accordance with the Interstate manuals; in others, no guide signs were present,
except for a very small and completely unreadable crossroad marker; and in others, small route shields and arrows were used.

This lack of consistancy was also noted on I-85, where advance warnings for interchanges were signed for by route markers and arrows rather than the standard manual guide signs. A prime example of this was found on the left-hand exit from I-85 to US 70 at the start of the US 70 test run. Rather than a standard guide sign, the exit was signed for by the US 70 shield and a small sign under the shield, black on white, saying left lane.

The suitability of the display in terms of reception characteristics of the driver takes into account the physical characteristics of the information carrier in regard to the visual sensory characteristics of the user.

An important aspect of the problem of suitability of the display in terms of receivability of the information (i.e., sign brightness and legibility) is discussed in Chapter Three. It must be realized that the most serious deficiency in display form is lack of legibility, and that one of the first things that should be accomplished in applying an information system is to ensure that all signs are legible.

An example of deficiency in form due to lack of contrast between sign and background was found on I-85. A supplementary guide sign for downtown durham was set back on a grassy area so that there was not sufficient contrast between the green of the sign and the green of the background, resulting in inadequate target value.

On US 70, many of the advisory and warning signs were very small and blended into the background during daylight hours. Furthermore, the position of the signs, in some cases, was such that one sign obscured or blocked a subsequent sign.

Information Display not in Optimum Location.-In addition to improper display location from a reception standpoint, a deficiency noted in existing highway information systems is that certain information is not displayed in an optimum location for use by the driver. That is, for information to be most effectively used, the driver must be able to perceive it and must have sufficient time to process it and take whatever control actions are required to execute the maneuver safely and efficiently.

It was for this reason that the subtask sequences were analyzed in terms of a perceptual as well as an action component. The perceptual component represents the time (hence, distance) from when the information first becomes perceivable to when the control action may or must be initiated. The action component represents the time when the control action may or must be first initiated to the last possible time to complete the control action.

The important factor is the perceptual component of the sequence. Because the perceptual component is the time span that the driver has to receive and process the information, the display location must be such that he has sufficient time to do so safely and efficiently. What must be established in analyzing display location is what represents sufficient time and on what basis should this be established.

In this regard, as in most aspects of highway informa-
tion system design, there are no clear-cut, hard and fast rules as to the proper location.

In the case of markings, the situation is more easily analyzed, and the applicable solutions given in manuals are, for the most part, adequate. That is, the microperformance and situational performance information displayed via the markings and signing channels is usually sufficient to enable the driver to perform the tracking subtasks, provided that the needed information is displayed, is readily perceivable, and is not too complex. In steady-state areas, a continuous treatment described in manuals is usually all that is required to provide location and lane information.

This is predicated on the fact that the markings and delineation are readily perceivable and that there are no sight line restrictions. Restricted sight lines, by themselves, are not sufficient grounds to judge markings and delineation treatments as being inadequate or deficient unless they occur in special-feature areas such as severe alignment changes, roadside hazards, and the like. It is in relation to these special-feature areas that the adequacy of marking and delineation treatments is determined. For example, the restriction of a sight line due to a crest in a steady-state area is not sufficient to consider markings or delineation as inadequate. However, if the crest is followed by a complex horizontal alignment change, which the driver could not perceive until he had reached the crest, then markings or delineation treatments would have to be supplemented by advance warning of the horizontal alignment change.

Even proper location and perceivability of markings and delineation treatments may not be sufficient in complex special-feature areas. Supplemental treatment such as advance warnings may also be required there.

In the case of verbal and symbolic messages conveyed by the sign channel, the situation relative to proper location is more complex. Each individual situation must be analyzed separately to determine adequacy of sign location. Many factors enter into the determination of sign placement. These include:

1. The nature of the subtask (special features).
2. The subtask loading (task difficulty).
3. The information to be displayed.
4. The type of message (symbolic or verbal).
5. The legibility and reading time.
6. The decision time.
7. Vehicle control requirements and vehicle response time.
8. The signal density and intervening task load.
9. Redundancy and previous messages.
10. Vehicle speed.

A case where virtually all of the factors just listed were operative was observed on I-85 at the To US 70 left exit. Figure 3 is a schematic representation of the situation. Figure 4 shows this area from the air, and Figure 5 shows the area from an approaching vehicle.

As Figure 3 shows, this is a complex left exit sequence with many special features, including:

1. An unexpected left exit (no advance warning).


Figure 3. Schematic diagram, eastbound I-85, east of Efland.
2. An exit "deceleration" lane that appears to be a change in cross section from two to three lanes (with possible path confusion).
3. An entrance ramp with an inadequate acceleration lane.

With regard to the nature of the subtasks, the example is based on the assumption that the subtask is to take the exit and go to US 70. There are several other possible subtasks in this area; that is, to remain on I-85, to enter onto I-85 from the entrance ramp and remain on I-85, or to enter onto I-85 from the entrance ramp and to subsequently take the US 70 exit. The last task, to enter onto the Interstate and to take the left exit, is by far the most hazardous and difficult maneuver, as it requires weaving across two Interstate main-line 65 -mph lanes from
an entrance ramp with an inadequate acceleration lane in a space of about $1,000 \mathrm{ft}$. This case represents one where no information system treatment can solve the problem and where a change in highway geometrics may be the only solution.

From a vehicle control standpoint, the task difficulty in taking the US 70 exit from I-85 is one that is not too great, as the road geometrics are typical of an Interstate route (i.e., there are no. extremes in alignment). However, the task difficulty is high from a cognitive standpoint, in that the driver must make a complex route-following decision under extreme time pressures in a high-signal area.

With regard to the information that should be displayed, the driver must know, from a macroperformance standpoint, that there is an exit, what the exit is, and where it leads to. In addition, owing to the potential path confu-


Figure 4. I-85 near Efland, N.C.


Figure 5. Driver's view, eastbound I-85.
sion brought about by the appearance of the exit which gives the appearance of being a bifurcation, the main line must also be identified.

There is, as in any subtask of the driving task high on the hierarchy, a complement of information needs associated with subtasks lower on the hierarchy (situational, as in traffic and alignment, and microperformance, as in lane lateral location) for this area.

Taken singly, an analysis of the information presentation for this location shows that the needed information is, in fact, presented. The problem in this area is thus not
in a lack of presentation, but in the manner of presentation.

The type of message used on the guide sign is a mix of verbal and symbolic, employing the Interstate and US shields and arrows pointing to the paths. Owing to the time pressures involved, the nonverbal coded display is appropriate to the situation.

An important factor in determining display location is legibility and reading time. At 65 mph (the posted road speed) the numerals in the shield are theoretically legible (under the $50 \mathrm{ft} / \mathrm{in}$. rule) 6.5 sec before the sign is passed.

Under nighttime conditions (see Chap. Three) this time is the same for high-beam illumination. The sign is never legible under low-beam illumination. However, because the sign is beyond the exit, the last action to take the exit is approximately 1 sec before the sign (if the vehicle is in the proper lane to take the exit and does not have to weave into the exit lane). This 1 sec must be subtracted from the legibility times, making the legibility time 5.5 sec for the numerals.

With respect to decision time, vehicle control requirements, and vehicle response times, the nature of the decision is one that can be classified as a "simple" one in that the driver either takes the US 70 exit or the I-85 main line. This, coupled with the relatively easy vehicle control requirement of changing from the right lane into the center lane, should require a total time of approximately 1 sec .

The signal density and intervening task load for the particular area consists of the following:

1. Signal Density.-The signal density could be characterized as moderate, because the area is in a rural area with a low ADT but with a somewhat complex geometric configuration. Note, however, the major advertising sign on the right side of the roadway.
2. Intervening Task Loading.-The intervening task loading can be potentially quite high if the driver is in the right lane and has to weave to the exit lane and if traffic is entering onto I-85 from the on-ramp.

In the example cited there is neither redundancy employed nor are there any previous messages. Finally, the vehicle speed is calculated at the posted speed (i.e., 65 mph ). However, it must be recognized that a segment of the traffic stream may be exceeding the speed limit, thus decreasing the legibility time and distance.

Considering this exit as, at the least, an "intermediate" interchange would, according to the manual, require an exit direction sign at the head of the deceleration lane and an advance guide sign 1 mile upstream. This location would bring it past the Efland interchange, creating possible confusion as to the exact identity of the next interchange. Several solutions appear feasible: (1) the installation of the exit direction sign; (2) the construction of a sign bridge at the location of the take-off for the Efland interchange or at the beginning of the deceleration lane for that ramp that would carry the exit, or exit direction, sign for Efland and an advance guide sign for US 70; (3) the installation of advance signing at a point that would be a compromise between the $1 / 2$-mile advance location for Efland and the 1-mile advance location for US 70; or (4) any combination of these. The choice between these would be made, at least partly, on the basis of economic feasibility. Whichever of these is adopted, it must be kept in mind that any signing for US 70 in advance of the Efland exit would introduce potential problems at that location, requiring detailed analysis. None of these measures, however, would alleviate the problems caused by entrance to exit traffic.

Too Much Information Displayed to the Driver.-A problem associated with existing highway information systems that may not be readily apparent is the case where
too much information is being displayed. By this is meant that the attention demands and/or the information challenge brought about by the particular location and associated task loadings and subtask interactions are such that the driver does not have the load-shedding or informationprocessing capacity to handle all the demands placed on him. As a result, the driver may miss needed signals or be unable to handle all the information or make errors because of exceeded capacity or driver confusion.

In the course of the analysis, when the subtasks were plotted on a scale representative of the road, it was found that this method yielded a profile of the road in which high-signal areas could be readily identified. This plot provides a graphic indication of high-signal areas by clearly showing where subtasks interact. However, there are many serious conceptual problems associated with an analysis of the significance of these high-signal areas:

1. There are no data in the literature relative to what constitutes "too much" information. There is no agreedon criterion as to the information-processing capacity, both in terms of quantity and rate, of the "median" driver. This has significance for any single information carrier as well as for areas where information carriers compete.
2. There is no clear-cut way to quantify the information content of nonsign (i.e., nonverbal) carriers. For example, the processing load for markings is not established, nor is it for the information content for unaided information (e.g., alignment, traffic).
3. The information sampling rate and load-shedding behavior of the "average" driver is not established, nor are there any data as to whether there is any "average" behavior with regard to attention value and load-shedding.

Thus, two basic issues are involved: driver processing overload and driver attention overload.

With regard to driver processing overload, the situation is too complex to make any definitive statements relative to what constitutes an overload. Therefore, rather than attempt to deal with information processing in terms of "bits" and "chunks" as is classically done in the literature, a more pragmatic approach is taken for purposes of this discussion. The factor of information processing and information demand is treated in terms of decision complexity and resultant subtask loading. It is assumed that relatively few situations exist where the information challenge is such that-given the proper information needed to make the decision, the requisite store of a priori knowledge (e.g., experience, reading skills), and sufficient time to make and implement the decision-the driver's processing channel capacity is exceeded. It is obvious that many situations exist where the driver is in fact faced with situations where the foregoing is the case, where the driver is not provided with the proper information needed to make the decision, where he does not have the requisite store of a priori information, and/or where he does not have sufficient time to make and implement the decision.

The question of the proper information to make the decision is discussed previously herein. What is emphasized here is that, given any information display technique, the display must provide the driver with the
information needed to make the proper decision and control maneuver safely and efficiently. Therefore, before an evaluation can be made relative to quantity of information sources displayed to the driver, the first question that must be resolved is whether the driver is, in fact, provided the proper information to make the decision. This must be resolved on a subtask-by-subtask basis in accordance with the principle of primacy developed herein so that it is ascertained that the spectrum of information needs associated with the subtasks generated by the highway system elements at a particular location is satisfied.

A tacit assumption is that the designer and reviewer of the information system can identify the driving subtasks gererated by the particular highway system elements for a specific location and, having identified the subtasks, identify and satisfy the information needs associated with those subtasks.

The second factor, requisite a priori knowledge, is complex and difficult. For purposes of this discussion, the question of a priori knowledge is broken down into the following areas:

1. Vehicle control.
2. Signal search and detection.
3. Signal recognition and processing.
4. Trip planning

It is assumed throughout this study that the population for whom the information system is being designed has the requisite a priori knowledge for adequate control of the vehicle. This implies that, given the proper information, the driver will be able to make and implement the requisite vehicle control maneuvers for a given situation. At issue is the unresolved question of what level of driving skill constitutes the requisite a priori knowledge from a vehicle control standpoint. Until this is resolved, the assumption is that the level of skill assumed by the engineering judgment of the highway engineers who designed the highway (e.g., speeds, superelevations) is that which is possessed by the driver.
(It must be kept in mind that this section is written primarily for Interstate-type roads. For older roads, especially some arterials, the assumption does not necessarily hold.)

With regard to signal search and detection, it is assumed that the driver, through experience and training, will have developed a scanning routine, so that he is not bound to any one source of information, but rather samples the information sources in short glances and load-sheds to attend to other sources. Here, again, there are no definitive data as to level of skill for signal search behavior. What is being used as a criterion for level of skill is that the driver does not have to attend consciously to the microperformance of vehicle control and most aspects of the situational performance level in steady-state areas. However, it is assumed that the driver does have to consciously attend to special-feature areas, especially where the special-feature area is counter to normal population expectancies, and to all of the macroperformance.

With reference to the a priori knowledge level associated with signal detection and recognition, it is assumed that
the driver is able to read, is familiar with the symbology presently employed on the signs contained in the manual, and has some knowledge of the codes presently used. However, the level of knowledge associated with the codes is difficult to gauge. Most drivers probably do know the color codes, but do not understand the numerical codes, as in the Interstate numbering system.

With regard to trip-planning a priori knowledge, the minimum assumptions are made that the driver knows where he has to go, and that he has a trip plan. Thus, it is assumed that the driver has an idea of how to get to where he wants to go. It is also assumed that the driver primarily uses readily available road maps as a source to formulate his trip plan.

The final factor, sufficient time to make and implement the decision, is discussed previously in relation to information display location.

Thus, returning to the point that was raised previously (i.e., situations may occur where the driver is unable to make decisions, due to lack of information, missing a priori knowledge, and/or insufficient time), these situations must be treated in terms of the factors leading to the inability to make the decision, and resolved on that basis before the issue of too much information can be treated.

The primary issue involved in the case of "too much information being displayed" is that of driver attention overload. Here, the questions to be considered can be looked at in terms of the quantity of competing information sources, the demands that these competing sources place on the driver's attention span, and the consequence of attending to a particular source of information. To place these factors in their proper perspective, it must first be recognized that there are, as in the case of information channel capacity, no definitive data relative to what constitutes an attention overload. Thus, there is no easy way to provide the information system designer or reviewer with a criterion for stating that when " $x$ sources of information compete, then the driver is overloaded." Here, as in many other instances, the designer and reviewer will have to rely on engineering judgment. However, there are certain aspects of the situation that will aid the designer and reviewer in formulating judgment, as well as certain "rules" that can be applied. These are discussed in the following.

However, a point must first be raised concerning the question of the limitations of the visual channel. At the onset of this research, the question was raised as to the limitations of the visual channel. For purpose here, it must be assumed that there is no practical limitation on the visual channel, per se; that is, that the information is receivable (has the necessary stimulus dimensions and is within the visual field of the driver). What there is a limitation on is the driver's ability to attend to competing information sources.

This is based on the fact that the driver must look at and attend to the visual stimulus in order to receive and process it, and on the fact that the driver cannot process information in parallel. He can attend to only one visual channel at a time.

Because the driver attends to only one source at a
time, he maintains an appreciation of a dynamically changing environment by sampling information from the many sources in the environment and constantly predicting, judging, and relying on his short-term memory to fill in the gaps. Most microperformance and a good portion of the situational performance information, such as alignment and traffic, is obtained and handled in this manner (i.e., through a series of quick glances). Other sources of information that require reading and decision-making (such as guide signs) take a longer time-at least equivalent to the reading time for the sign. Therefore, it is seen that the source of information predicates to some extent the amount of attention paid to it, ranging from short, quick glances for microperformance, to longer glances for situational performance, to times in the order of seconds for complex guide signs. Thus, the designer and reviewer must be cognizant not only of the quantity of signals, but also of the types of signals and the times required to pay attention to them.

This point leads directly into the next factor that must be considered: the demands that these competing sources place on the driver's attention span.

Each subtask, and the information presentation associated therewith, must be considered in terms of the complexity of making the decision and/or executing the maneuver required by the subtask. The simpler the decision, and/or the simpler the maneuver required, the less attention must be paid to the subtask. For example, very little task loading is created in a simple straight-line tracking and speed control task; more, for a compensatory tracking maneuver; and more, for an exit-taking decision. The simpler and easier the decision and/or vehicle control maneuver, the less attention must be given to making the decision or executing the maneuver.

In addition to the question of decision complexity and resultant subtask loading, the fact that the driver divides his attention by sampling information and predicting, judging, and relying on his short-term memory to fill in gaps has applicability to the situation. Any features that in any way interfere with his ability to predict and judge adversely affect his ability to load-shed. Thus, if the driver is faced with special-feature areas, especially those that violate his expectancies (hence, interfering with his ability to predict), he cannot load-shed effectively and must continue to attend to a specific source of information.

In summary, the driver may be called on to handle information from several sources of information by loadshedding his attention from one source and shifting it to another source. Furthermore, owing to the high-speed environment of the Interstate system, and owing to the signal density for a given location, the driver may have to do this under extreme time pressures. When the external pacing of the road exceeds the ability of the driver to handle the information by proper load-shedding, it can be said that his attention capacity is exceeded. Although it is not possible to quantify when this occurs, it can be seen that this may in fact occur in special-feature high-signal-density areas such as interchanges, extremes in geometrics, and places where expectancies are violated. That such a situation may occur is sufficient
grounds to consider the special-feature area as a candidate for checking for too much information display.

When such an area is noted, the designer must evaluate each competing information presentation present in the area in terms of the consequence of attending to the particular source and thereby possibly not attending to another source. The concept of primacy is the most viable means of making this determination. The more prime information needs must be satisfied first before less prime needs can be considered. The driver must be able to remain safely on the road in his lane before one can consider presenting him with directional information.

The designer and reviewer will have to rely heavily on engineering judgment to evaluate when too much information is being presented. If he believes that he has identified an area where too much information exists, he must evaluate each information presentation for task-loading and immediate need so that he can delete extraneous information presentation, spread less prime information, and still ensure that the most needed information is available.

The purpose of such a long introduction to this class of information system deficiency is to provide a measure of the complexity of the issue of too much information display and to present some of the important factors involved in identifying these problem areas.

The procedure that was used in identifying areas of too much information display was to evaluate the road plot and look at areas where there seemed to be an excessive number of subtask interactions. The individual sequences were then evaluated for subtask loading to derive examples where the driver's attention span may be overloaded.

As would be expected, the plot for US 70 clearly showed high-signal densities due to poor geometrics, uncontrolled access features, and the presence of a large quantity of signs. In most instances, the only solution to the problem of potential overload would be redesign, because uncontrolled access features, cross traffic, alignment changes, etc. (all non-sign-related factors), are the cause of the overload. However, there were areas where unneeded information such as $\$ 50$ fine for littering, and keep north carolina beautiful could be removed. Furthermore, there were areas where spreading would be desirable, as in an intersection where six different route markers were present at a complex at-grade interchange.

In the case of I-85, several areas existed where too much information was presented. For example, at the Durham city limits the road surface changed and became much poorer; there was an alignment change; the speed limit changed from 65 to 60 mph ; a sign stating DURHAM cITY Limits was erected; US 70 joined I-85 with a twolane ramp and then merged to three lanes with a right lane drop at an exit; there was a guide sign for the exit; and there was considerable merging and weaving traffic. In addition, there were US 70 and I- 85 shields and signs stating no parking on the median and no littering. In the course of filming this road, the driver almost took the exit because of the path confusion brought about by the complex merge.

Although it may not be possible to rectify the prob-
lems of this area, clearly too much information is presented. Certain signs, such as no parking and no littering, can be eliminated or moved, and the change in speed limit could occur earlier.

Transmission of Information Inhibited Due to Physical, Climatological, or Ambient Lighting Factors.-The final category of information deficiency concerns the inability of the driver to receive displayed information because of physical conditions, climatological conditions, or ambient lighting factors.

The first category of deficiency-inhibition due to physical conditions-is associated primarily with sign blockage brought about by such things as other signs, bridge abutments, and light poles. In addition, sign blockage may occur due to truck blockage. In the course of the analysis, few cases of physical sign blockage were found (several on US 70 due to signs blocking other signs, and none on I-85), although several cases of sign blockage due to trucks were observed.

Inability to receive transmitted information due to adverse climatological conditions was observed twice in the course of the analysis; this was due to fog conditions in one case and to heavy rain in another. Although these were minor cases, the designer and reviewer should be aware that inhibition of transmitted information can occur, and consideration should be given to prevailing climatological conditions in high fog or heavy snow areas.

The final point concerns ambient lighting factors. The information system designer must bear in mind that the view that the driver receives at night is entirely different from the daylight situation, and that decisions on markings and delineations for unlighted sections may be different for those for lighted ones. In addition to fixed highway lighting, the possible effect of headlight glare, light sources outside the right-of-way (such as sign floodlighting), and the effect of driving into the rising or setting sun must be evaluated.

## Outline of Highway Information System Review Procedure

In the previous section, the results of a detailed analysis of existing highway configurations yielded a description of common deficiencies associated with present highway information systems. In the discussion of the results of the analysis, examples of these deficiencies are presented, reasons for the deficiencies are noted, and possible remedial action is identified. In this section, consideration is given to the manner in which the noted deficiencies can be avoided if the information system is in the design stage. This is accomplished by providing the designer and reviewer with a basis on which to evaluate a given design and apply the principles and findings of this research.

## Deficiencies in Existing Highway Information Systems

Although not every road or every location may have problems associated with its existing information system, there are many roads and locations where deficiencies occur, either singly or in combination.

If a problem is suspected (e.g., high incidence of
accidents, noted confusion of drivers, user feedback), it is necessary to evaluate the location in question in terms of the suitability of its information system. Once a determination is made that problems are associated with the display of driver information, more detailed analyses of the highways information system should be performed.

Virtually all highway information systems analyzed in the course of this project had some deficiencies. However, in most instances objectional features were keyed to specific problem locations rather than to the highways as a whole. This point is particularly true in the case of the Interstate highways. Conversely, data taken on older, nonInterstate roads (e.g., state routes, arterials) yielded major deficiencies in over-all information system design as well as a greater need for optimum information display. This is due, in part, to hazardous geometric designs, uncontrolled access features, at-grade rail grade crossings, lack of medians and shoulders, etc.

The previous section presents a way to evaluate an information system by determining what the information needs for a particular location are, and whether and how they are satisfied. When an information system is found to be deficient, the deficiencies can be rectified by determining the reason(s) for the deficiency and developing solutions to overcome the objectionable features.

This has been accomplished in this project by using the data developed by the human factors task and information analysis keyed to the task of driving a car through the highway using the information system presently on the road. The results of this analysis were synthesized with the principles previously developed to yield solutions to information system problems. By applying these procedures to any given highway information system, the deficiencies of the system may be rectified.

It is not feasible for operating engineers to perform the complex and time-consuming analytical activities that were accomplished in the course of this project to analyze existing highways and to derive solutions to specific problems.* However, by appling the design review procedures in Appendix H to a given location it will be possible for design and review personnel to identify information system deficiencies and to develop more acceptable information system designs.

In the case where a new highway information system is being designed, an application of the design review procedure will result in the design of an information system that represents the optimum in design within the constraints of the characteristics of the specific highway.

## Highway Information System Design and Review Practices

Although a complete analysis and synthesis method of approach is highly desirable, an analysis of the practical considerations of highway information system design, based on interviews with active operating engineers, indicated that at present this would not be possible.

In many cases the design of a new highway information system is left to lower-echelon personnel and is reviewed by the cognizant senior design engineer. Thus, by the time

[^15]the senior design engineer reviews the information system plans, he may be faced with an acomplished fact and/or be under severe time constraints.

Therefore, because a primary purpose of this project is to provide highway design personnel with a tool to assist them in their everyday activities, a design review procedure has been developed that can be used by the design engineer to review existing information systems. The merit in providing such a design review procedure is that it will enable highway designers to review, relatively rapidly, both existing and proposed highway information systems.

## Rationale

The rationale and assumptions of the information system design review procedures are presented to indicate how the procedure has been developed and some of its implications for information system design.

The information system design review procedure is a tool to be used by highway design engineers to review existing highway information systems. As such, the procedure has been constructed on the basis of a job analysis of the way in which engineers review delineation and signing plans, synthesized with the data in applicable manuals and the project research findings.

Data were taken on a sample of experienced senior design engineering personnel to determine their methods and procedures. These data were used to analyze the activity of reviewing highway information system designs.

Once the task of determining how a design engineer reviews a highway information system was analyzed and synthesized with manual and research findings, it was converted into system flow logic diagrams indicating, step by step, the decisions that should go into an optimum information system design review.

Using these system flow logic diagrams as a framework, the findings of this project were then used as data on which to make the various decisions required of the procedure. Figures 6 and 7 are typical examples of these system flow diagrams.

## Implications for Design

The procedures that have been developed are intended primarily for use on Interstate and Interstate-type highways, although they may be readily modified for other types. Because the procedures are for Interstate roads, the appropriate manuals have been adhered to insofar as is practicable.

In addition, the procedures have been written in terms of formal aiding. Thus, procedures have been formulated for:

1. Delineation and marking.
2. Regulatory signs.
3. Warning signs.
4. Directional signing.
5. Service signing.

## Design Review Procedure Approach

The approach to the design review procedures is one of tying the procedures to specific manual-related formal aiding systems (i.e., markings and signing), thus preserving the "nuts and bolts" orientation of the reviewing engineer. It is believed that considerable utility is achieved when a reviewer is able to relate specific information needs to well-defined information carriers.

The over-all review procedure ultimately will be a step-by-step review of the design in the form of a manual. The procedure essentially follows the level of performance and hierarchy concepts. This is accomplished by first reviewing that information relating to the driver's ability to stay on the road in his lane and to follow the geometrical contours of the road. This means that the reviewer will be first attending to the delineations and markings to determine their adequacy.

Once this has been achieved, the design review procedure is addressed to the regulatory and warning signing. First, the reviewer considers the adequacy of existing or proposed regulatory signing as a function of the legal as well as the highway environment.

As the review proceeds up the primacy scale, more and more highway system elements are introduced and their effects back along the hierarchy are determined. Thus, the effects of traffic, unusual geometrics, special features of the road, etc., are determined. This is achieved through a review of the warning sign design.

It is noted that a feedback process is followed to determine what effect any given information carrier higher up in the hierarchy has on any information display lower down the primacy scale. This feedback process is the basis on which the adequacy of any redesign is evaluated. That is, once an information display is found to be deficient, and its rectification is determined, the impact of the rectification on other information carriers already judged to be adequate is determined.

By the time the warning signs have been reviewed, all aspects of the highway situational and road situational levels of performance will have been reviewed and analyzed. This will enable the reviewer to direct attention to the two main classes of macroperformance information needs-direction finding and service.

The review procedure for the macroperformance information display is essentially the same as for the situational performance information needs. Thus, the process of continual feedback up and down the hierarchy is followed, as the directional and service needs satisfying information carriers are introduced and/or redesigned.

As the foregoing discussion indicates, the analysis is primarily for visually displayed information. However, display of information on other information channels (e.g., auditory, tactile) is not ruled out, especially in terms of a means of displaying information that could not otherwise be displayed visually.

Furthermore, redesign of the roadway itself is not ruled out, if it is determined that no information presentation can resolve difficulties inherent in the design of the infor-


Figure 6. System flow-predesign review.


Figure 7. System flow_marking and delineation design review.



Figure 7. (continued).

The procedures are applied on a segment-by-segment when performing the review,


Figure 7. (continued).

# FINDINGS—FIXED HIGHWAY SIGNING 

## SIGN DESIGN FOR NIGHT LEGIBILITY

If, as indicated, signs will remain the principal means of transmitting information to the highway user, it becomes essential to optimize all aspects of sign design. This section presents a detailed analysis of one of these aspects: the legibility of signs under nighttime conditions.

The severe reduction of visibility at night minimizes the utility of informal and quasi-formal aiding as sources of information; formal aiding, as represented primarily by signing, thus assumes the principal role in the satisfaction of drivers' information needs. Experience has shown that sign visibility and legibility are critical at night. Therefore, signs must be designed to yield information during the hours of darkness and then must be checked to see whether they also satisfy daylight requirements.

For a highway sign to fulfill its purpose, its message must be legible. Under typical rural conditions with no fixed lighting, the message is illuminated only by the car's headlights. Just as any other object falling within the headlight beams, the highway sign will be illuminated as a function of its position, the road alignment, and the position of the car on the road. In an urban situation, where electric power is more readily available, the sign may be internally or externally illuminated. The illumination on the sign, whether by fixed sources or by the car's headlights, has the effect of yielding a perceptible brightness at the driver's eye.

Within recent years, widespread use of retroreflective sign material has resulted in signs that are much brighter than those produced by nonreflectorized surfaces and by other diffuse objects in the driver's field of view. Bright signs can result in nighttime performance that, in some cases, approaches that of good daytime use. As seen by the driver under actual night roadway conditions, reflective materials in common use today range in luminance from less than 0.1 foot-lambert to more than 100 footlamberts. This wide range of brightness is not due primarily to differences in reflective properties of the material itself, but rather to wide ranges in illumination from the headlights and to the geometric relationships between the sign position and roadway alignment. The relationship of these factors to the brightness of signs can be analytically determined for a wide range of conditions that are likely to occur on an actual roadway.

Allen et al. (133) studied the relationship between legibility, distance, and sign luminance (the distance at which a sign can be read for a given letter height, as a function of the brightness of the letter) and empirically determined a functional relationship between the two. This relationship is shown in Figure 8. Separate curves are plotted to show the effect of headlight glare from opposing vehicles. It should be noted that, to obtain
legibility analogous to commonly accepted values for daylight operations ( $50 \mathrm{ft} / \mathrm{in}$. of letter height), luminance values ranging from about 1.5 (if there is no headlight glare) to about 12 (if there is headlight glare) will be required.

Therefore, two relationships are known concerning reflectorized signs: (1) the brightness of the sign as a function of the applicable parameters (sign material, road geometry, vehicle), and (2) the legibility of the sign as a function of its luminance. Letter height can thus be expressed as a function of the distance at which the sign is to be read for any given set of sign, road, and vehicle characteristics. This function can, in turn, be used to form the basis of a procedure for the design of highway signs for nighttime legibility.

This section includes a discussion of the factors affecting brightness. An analytical procedure is derived by which brightness of signs can be predicted. This predicted brightness value can then be used to determine the letter height required to yield legibility at a point sufficiently in advance of the sign so that available reading time, as a function of distance and velocity, is equal to or exceeds required reading time, as a function of message length and complexity.

## Development of Computer Program

The general method for determining the brightness of reflectorized signs for a variety of sign materials, sign positions, distances, highway alignments, and traffic conditions was first described by Straub and Allen (134). Using these same techniques, a computational program using FORTRAN IV for the IBM 360/30 computer was written to determine the brightness of reflectorized signs. The present activity greatly broadens the scope of the referenced work by including many additional parameters.

This program was used to derive the various relationships shown and discussed in subsequent portions of this section. As originally written, the program permitted the evaluation of one alignment element, either horizontal or vertical curve, at one time. Subsequently, the program was expanded and rewritten for the IBM 360/40. As presently constituted, the program (described in Appendix C) permits the insertion, into the computer storage, of an actual highway alignment, taken off construction plans, and the determination of the brightness of any sign at any point along this alignment for any specified type of vehicle approaching in any specified lane.

Sufficient computer runs were made, with the original program, using representative values of the applicable parameters, to demonstrate the applicability of the method and to determine, if applicable, the general trend of these


Figure 8. Legibility as a function of luminance.
relationships. A restricted field investigation of actual brightness was made and the results thereof were compared to the predicted values. The limitations of the current research effort prevented the inclusion of sufficient values of these parameters to determine quantitative relationships or to derive handbook-type design data.

The revised program was used to analyze the actual signs currently in place on one roadway of a 20 -mile section of I-85 in North Carolina. The results of this analysis are reported subsequently herein.

## Factors Affecting Sign Brightness

The three major factors in the determination of the resulting field brightness of reflectorized signs are (1) sign, (2) road, and (3) vehicle. These factors are given in Table 11.

## Sign

The two major subdivisions describing the properties of the signs are material and position.

Material.-The physics describing the operation of retroreflectors are explained in many references such as Van Lear (135), Finch (136), Chandler and Reid (137), and Giovanelli (138). An opaque object will reflect light diffusely in all directions; a retroreflector returns much of the light it receives back to the source in a narrow cone described as a function of the divergence angles. The divergence angle is the angle at the sign formed by the line connecting the light source and the sign and the line connecting the driver's eye and the sign. A sign would appear brightest if the observer were directly in line with the source. When the observer moves away from the line

TABLE 11
FACTORS AFFECTING SIGN BRIGHTNESS

| ITEM | FACTORS AFFECTING BRIGHTNESS |
| :--- | :--- |
| Sign | Sign face material (photometric properties) |
|  | Position: |
|  | Lateral offset |
|  | Vertical offset |
| Road | Horizontal alignment: |
|  | Tangent |
|  | Horizontal curves: |
|  | 1. Intersection (deflection) angle ( $\Delta$ ) |
|  | 2. Degree of curve ( $D$ ) |
|  | 3. Length of curve $(L)$ |
|  | 4. Transition spirals |
|  | Vertical alignment: |
|  | Constant grade: |
|  | 1. Level |
|  | 2. Not level |
|  | Vertical curves: |
|  | 1. Beginning grade $\left(g_{1}\right)$ |
|  | 2. Final grade $\left(g_{2}\right)$ |
|  | 3. Total grade change $\left(g_{1}-g_{2}\right)$ |
|  | 4. Length of curve $(L)$ |
| Vehicle | Headights: |
|  | Number |
|  | Type |
|  | Arrangement |
|  | Location |
|  | Beam (high or low) |
|  | Driver's eye pusition |

of source of light, the divergence angle increases and the amount of light returned to the observer decreases. For the usual position of the driver's eye, within his car, the divergence angle is small and reflectorized signs illuminated by his car's headlamps appear much brighter than other objects in his field of view.

The other parameter affecting the reflectance of light from the material is the entrance angle. This is the angle at the sign between a line connecting the light source and the sign and a line normal to the sign. As the entrance angle increases there is a corresponding decrease in reflectance from the sign.

Specific luminance refers to the ratio of the brightness of the sign to the illumination (foot-candles) received by the sign. Figure 9 shows the specific luminance characteristics of silver scotchlite,* a reflective sheeting material used on Interstate signs. These characteristics show specific luminance (foot-lamberts per foot-candle) as a function of divergence and entrance angles.

Figure 10 shows the specific luminance characteristics of three different types of materials plotted against divergence angles for a $0^{\circ}$ entrance angle. SIGNAL SILVER,* a newer product, has greater reflectance properties at zero divergence. Buttons and corner cube reflectors (such as produced by Stimsonite Signal Products) are even more efficient reflectors at zero divergence. Because reflective sheeting forms a letter continuously, a specific luminance factor can easily be assigned to it. A letter made of buttons

[^16]is not continuous and therefore appears as a number of point sources that the eye integrates to form the letter. To compare sheeting to buttons, it was necessary to assign an equivalent brightness to the corner cube reflectors by averaging the intensity of the buttons over the entire area of the letter, due to the lack of a more appropriate method.

It must be emphasized here that the data shown in Figure 10 are for a $0^{\circ}$ entrance angle. The specific luminance characteristics of the buttons at greater entrance angles are much more critical than those for sheeting materials. The curves of Figure 10 are shown for comparison only and in no way are a measure of the effectiveness of each material.

In addition, it must be emphasized that available legibility data do not apply to buttons and indicate only capabilities of continuous sheeting. Empirical data, relating the legibility of letters formed from buttons to the brightness of the buttons, are needed to compare letter heights required using buttons to those using continuous sheeting.

Position.-The lateral position of the sign affects the apparent brightness by changing the entrance angle. In the original investigations six representative sign positions (Fig. 11) were chosen. The illustrative computations were made for the center of a sign 10 ft high and 20 ft wide located over, or adjacent to, a four-lane (12-ft lanes) unidirectional roadway.

## Road

The road category deals with the geometric alignment. The three major alignments are straight roads, horizontal curvature, and vertical curvature. Overlapping combinations of horizontal and vertical curvature were not considered in the original investigations. The curves that were used in the computer solution are typical for the Interstate system.

Straight Road.-The straight road defines a highway with no horizontal or vertical curvature. It is composed of four lanes in the same direction, each with a $12-\mathrm{ft}$ width. The sign location is chosen and the computer calculates the trigonometric relationships at various points as the vehicle is driven toward the sign from a distance of $3,000 \mathrm{ft}$.

Horizontal Curvature.-Horizontal curves consist of circular arcs usually preceded by and extended by spirals, arcs of varying radii, to achieve a smooth transition between the circular arc and the tangents. For the purpose of computation of road positions, however, the horizontal curve is assumed to be a circular arc. Figure 12 shows the horizontal curvature. The geometric relations involved are discussed in many references, such as Meyer (139).

There are many possible combinations of parameters that could be investigated. For this investigation two values of $D$ and two values of $\Delta$ were chosen as representing those commonly used. The values selected were $D=1^{\circ}$ and $4^{\circ}$, and $\Delta=10^{\circ}$ and $40^{\circ}$. Any combination of these for a left or right curve defines the particular roads used in the computer runs for study purposes. $D=4^{\circ}$ is the maximum degree of curvature recommended (21) for a $70-\mathrm{mph}$ road, whereas $D=1^{\circ}$, a value commonly used,


Figure 9. Specific luminance characteristics-wide-angle flat top SILVER SCOTCHLITE.
represents a lesser curvature. A $10^{\circ}$ change in direction is moderate, whereas a $40^{\circ}$ change is significant.

Vertical Curves.-"Profile tangents are connected with vertical curves . . . the parabola is utilized generally for this purpose" (33). The designer specifies the entire shape of the parabola by specifying the grade change and the difference in stations between the beginning and the end of the curve.

The vertical transition curve can have infinite variations -that is, it can he formed from any combination of grades and lengths. To simplify the geometry, an equal tangent vertical curve was used. For study purposes, the grade


Figure 10. Specific luminance characteristics- $0^{\circ}$ entrance angle.
changes selected are $\pm 6$ percent and $\pm 2$ percent, representing both crest and sag curves. The 6 percent gradient change is the maximum allowable for a $70-\mathrm{mph}$ Interstate road [each "gradient shall not be steeper than three percent" (22)] and the 2 percent grade change represents a road with moderate vertical curvature. For a sag-curve the horizontal projected length for a 2 percent grade change and design speed of 70 mph is 300 ft (three stations) and it is 900 ft for a 6 percent grade change. The horizontal projected length for a crest curve is 500 ft and $1,500 \mathrm{ft}$ for the 2 and 6 percent grade changes, respectively. All lengths are as recommended for a $70-\mathrm{mph}$ design speed (21).


Figure 11. Sign positions.

## Vehicle

The major considerations, in this category, affecting the calculation of sign brightness are headlamp type and vehicle classification. The headlamp type specifies the headlamp characteristics to be used with the car. The vehicle classification determines the configuration of the headlamp array along with the locations of the headlamps and their position with respect to the driver's eye.

Headlamp Type.-At present, there are three different types of sealed beams that are in common use: (1) a $53 / 4$-in., type 1 headlamp (no. 4001) with a single filament, (2) a $53 / 4$-in., type 2 headlamp (no. 4002) that has two filaments, and (3) a 7 -in., type 2 headlamp (no. 6012), also with two filaments. Specifications for these lamps were obtained from the Society of Automotive Engineers (140). A late-model sedan probably would have four $53 / 4$-in. sealed-beam units: two no. 4001 units and two no. 4002 units. The relative positions of the four headlamps are shown in Figure 13. The low beam is provided by one of the filaments of the type 2 units (main headlamp) and
the high beam is provided by the second filament in the main units and by the filament in the type 1 sealed beam units (auxiliary headlamps). If a car has only two headlamps they will probably be of the 7 -in., type 2 units. This unit is a 7 -in.-diameter headlamp (no. 6012) providing both the upper and lower beam.

The output of each headlamp is given by the distribution of light in the headlight beam, described by isocandle curves. Figure 14 shows a sample isocandle curve for one of the headlight filaments. Five isocandle distributions were needed in this study: (1) no. 4001 high beam, (2) no. 4002 low beam, (3) no. 4002 high beam, (4) no. 6012 low beam, and (5) no. 6012 high beam. To determine the candlepower from an average headlamp, it was necessary to average the data from a number of distributions for the same type of headlamp. (Isocandle characteristics are plots obtained from the candlepower distribution of a random headlamp.) A number of characteristics for each type of headlamp were obtained from manufacturers and averaged. Figure 15 shows an average candle-


Figure 12. Horizontal curve geometry.


Figure 13. Dimensions of vehicles used in computation.
power distribution chart for a no. 4002 low beam. This chart is in tabular form for computer use. It permits straight-line interpolation for intermediate values.

It should be noted that Figure 14 is a factory specification for a perfectly clean lamp. Any amount of dirt or moisture on the lens will reduce and distort the output. A recent study by the Road Research Laboratory (156) found that reductions in light intensity of as much as 90 percent were measured and that even headlights described as "dirt barely noticeable except by close inspection" showed a reduction of 24 percent in the maximum intensity of emitted light. The study found that the reduction was not uniform but, rather, occurred in varying degree throughout the isocandle chart.

Vehicle Classification.-Because sign brightness is a function of the geometric relationships between the sign and the car, the dimensions of the car must be known. The dimensions of interest in this study are shown in Figure 13; they are the location in orthagonal space of each headlamp and of the driver's eye position. The headlamp locations of average cars were determined after consultation with automobile manufacturers. The dimensions of the cars used in this study represent most of the cars on the road today. Four cars were chosen for the original study: (1) a sedan (Fig. 13), (2) a sedan with four headlamps, two on each side aligned vertically, as compared to a horizontal placement of Figure 13, (3) a


Figure 14. Isocandle distribution-low-beam no. 4002 headlamp.
compact car with a four-headlamp system, and (4) a sports-type car with a two-headlamp system.

The position of the driver's eye was determined after consultation with automobile manufacturers and a review of the literature. Lee (142), in a study using photogrammetric methods, determined that a driver's eye height of 3.95 ft represents 85 to 90 percent of drivers tested. Stonex $(143,144)$ suggests that because of vehicle dimension trends, the driver's eye height will tend to be 3.5 ft ( 42 in .) and also suggests that this value would probably be the minimum value for the average driver. AASHO (21) uses a value of 3.75 ft of driver's eye height as a criteria; the Manual of Uniform Traffic Control Devices for Streets and Highways (92) uses a value of 4.0 ft . Meldrum (145), also using photogrammetric techniques, determined population distributions of driver's eye position. Using all the literature, it was decided to use 3.95 ft as the value of driver's eye height for a sedan and 3.5 ft as the value of driver's eye height for the compact and sports cars, respectively ( 140,146 ).

Table 12 gives the dimensions of the four vehicles used in the computer program. The coordinate system is centered on the ground directly under the headlamps and at the center line of the vehicle (Fig. 13). The dimensions are tabulated to the nearest thousandth of a foot for entry into the computer. $X$ is measured along the longitudinal axis, in feet (positive toward rear of vehicle); $\boldsymbol{Y}$ is measured along the perpendicular to the longitudinal axis, in feet ${ }^{\dagger}$ (positive is toward the right shoulder) ; ${ }^{*} Z$ is the height above the pavement, in feet.

TABLE 12

## VEHICLE DIMENSIONS

|  | VEHICLE DIMENSIONS (FT) |  |  |  |
| :--- | :--- | :--- | :--- | :---: |
| ITEM | $\mathbf{x}$ | y | Z |  |
| $(a)$ Sedan with horizontal | headlamp configuration |  |  |  |
| Coordinates of driver's eyes | 7.900 | -1.400 | 3.950 |  |
| Coordinates of right main beam | 0.000 | 2.442 | 2.125 |  |
| Coordinates of right auxiliary beam | 0.000 | 1.800 | 2.125 |  |
| Coordinates of left main beam | 0.000 | -2.442 | 2.125 |  |
| Coordinates of left auxiliary meam | 0.000 | -1.800 | 2.125 |  |


| (b) Sedan with vertical headlamp configuration |  |  |  |
| :--- | ---: | ---: | ---: |
| Coordinates of driver's eyes | 7.900 | -1.400 | 3.950 |
| Coordinates of right main beam | 0.000 | 2.692 | 2.616 |
| Coordinates of right auxiliary beam | 0.000 | 2.692 | 2.050 |
| Coordinates of left main beam | 0.000 | -2.692 | 2.616 |
| Coordinates of left auxiliary beam | 0.000 | -2.692 | 2.050 |


| (c) Compact car |  |  |  |
| :--- | ---: | ---: | ---: |
| Coordinates of driver's eyes | 7.358 | -1.183 | 3.500 |
| Coordinates of right main beam | 0.000 | 1.933 | 2.058 |
| Coordinates of right auxiliary beam | 0.000 | 1.400 | 2.058 |
| Coordinates of left main beam | 0.000 | -1.933 | 2.058 |
| Coordinates of left auxiliary beam | 0.000 | -1.400 | 2.058 |

(d) Sports car

| Coordinates of driver's eyes | 7.358 | -1.183 | 3.500 |
| :--- | ---: | ---: | ---: |
| Coordinates of right main beam | 0.000 | 1.179 | 2.125 |
| Coordinates of left main beam | 0.000 | -1.179 | 2.125 |

Figure 15. Candlepower distribution chart-low-beam no. 4002 headlamp.

Miscellaneous.-In addition to the three principal factors just listed and discussed, the following factors affect the apparent brightness of the sign.

Transmissivity.-Transmissivity is the loss of light signal caused by atmospheric attenuation. Many references define the effects of attenuation and show the mathematical relationship between the light intensity and its loss through the atmosphere. Stiles et al. (147) and Lash and Prideaux (148) determined the relationship of a light source transmitted at one place and received at a second place in terms of its attenuation per mile. Because the light from the headlamp must travel to the sign and back to the driver, the distance it must travel is essentially twice (neglecting distance from driver to headlamp) the distance from the headlamp to the sign. The relationship that is applicable to the case of headlamp illumination only is:

$$
\begin{equation*}
T=t \exp \frac{2 d}{5,280} \tag{1}
\end{equation*}
$$

in which
$T=$ over-all transmissivity attenuation;
$t=$ transmissivity factor per mile;
$d=$ distance from headlamp to sign, in feet; and $5,280=$ feet per mile.
The International Visibility Code, as listed by Projector and Robinson (149) is given in Table 13.

Voltage.-Nock et al. (150) studied actual voltages in lighting circuits for a sample of cars on the road. They found that the average values for minimum and maximum voltages at the headlamp for the cars tested were 11.6 and 13.0 volts, respectively.

The isocandle distribution as shown in Figure 14 represents the headlamp output taken at the rated voltage of 12.8 volts. An increase or decrease from rated voltage will yield a greater or lesser amount of light respectively, from the nominal ( 100 percent). A light output of 106 percent times the normal is yielded by 13.0 volts; 11.6 volts yields a light output 72.8 percent of the normal. These values are derived from manufacturers' data (151).

Misaim.-When the headlamps of the car are not aimed properly, the headlamp characteristics are shifted away from the nominal by that factor of misaim. If, for example, the headlamps are aimed downward by $1^{\circ}$ from the horizontal, there is an effective shift in the distribution of the candlepower upward by $1^{\circ}$. This affects the sign brightness by putting either more or less light on the sign as a function of the road geometry.

Age.-When a sign is exposed to the elements for a long time, sign properties are affected. The effects of aging on waft silver scotchlite (obtained from the manufacturer) are representative of the kind of effects that occur to material on exposure for a long period of time; a loss of reflectivity results. In localized industrial areas that are subject to corrosive air pollutants, aging can progress at a much increased rate.

Additional Cars on the Road.-One factor that aids the luminance of the sign is the illumination of the sign by additional cars on the road. To determine the brightness of the sign as it appears to one driver, the luminance of the sign is calculated from the headlamp output of the

TABLE 13
INTERNATIONAL VISIBILITY CODE

|  | DAYLIGHT VISUAL <br> RANGE (STATUTE |  |
| :--- | :--- | :---: |
| WEATHER | MILES) | TRANSMISSIVITY <br> PER MILE |
| Exceptionally clear | $31+$ | $0.88+$ |
| Very clear | $12-31$ | $0.73-0.88$ |
| Clear | $6.2-12$ | $0.53-0.73$ |
| Light haze | $2.5-6.2$ | $0.21-0.53$ |
| Haze | $1.2-2.5$ | $0.044-0.21$ |
| Thin fog | $0.62-1.2$ | $0.0019-0.044$ |

second car, and the geometric relationship of the headlamp position in the second car, the sign, and driver's eye position in the original car.

Dew, Frost, and Ice Accumulation.-Temporary accumulation of dew, frost, and ice on the sign face can have a marked effect on the optics of the reflective system and have been found to reduce greatly the brightness characteristics. The causative conditions are highly variable and no attempt to quantify the resulting brightnesses was made in this study.

## Variability in Sign Brightness

The original computer program was used to determine, for a representative number of cases, the quantitative effect of variations in the values of the parameters discussed previously on the apparent brightness of the sign. The output of the program was tabulated and also plotted on a California Computer Products (CalComp) Model 763 plotter. The plotting axes chosen were road distance in feet and luminance in foot-lamberts.

Three materials were studied: waft silver scotchlite, buttons, and signal silver. Three different types of road alignments were analyzed: straight road, horizontal curvature, and vertical curvature. The horizontal alignment for both left and right curves was analyzed for degrees of curvature of $1.0^{\circ}$ and $4.0^{\circ}$ and deflection angles of $10^{\circ}$ and $40^{\circ}$. The vertical alignment for both sag and crest curves was studied for grade changes of 2.0 and 6.0 percent with appropriate lengths of curve. The six sign positions used in the computer analysis are described earlier. In addition, the sign was located at different positions with respect to the horizontal or vertical alignment changes. These locations were the middle of the curve, the end of the curve, and 1,000 or $2,000 \mathrm{ft}$ beyond the end of the curve on its forward tangent. The values for the parameters chosen are by no means exhaustive. Any value for grade changes, degrees of curvature, etc., could have been inserted into the computer to describe any segment of road under analysis. The actual parameters were chosen to get representative values for roads, cars, materials, etc. In all, the study included: four different cars, on high and low beam; 13 road alignments; three reflective materials; and six sign positions.

By selecting a few combinations of the parameters the number of possible runs was reduced. Thirteen road
alignments, two sign materials, six sign positions, and two beam uses were studied. The number of computer runs was 312 , the product of all the parameters chosen. This total does not include special runs to study effects of misaim, aging of material, etc.

## Results of Computer Simulation

The following curves are representative of those computed. Figure 16 shows the effect of the different cars on brightness. These plots are for a straight road, waft silver sCotchlite material, a standard roadside sign, and for the cars on low beam. The curves show that there is only a negligible change in brightness for the different types of cars.

The following figures are for the standard sedan with a horizontal headlamp configuration (Fig. 13), which is referred to as car no. 1.

Figure 17 shows the effect of the three sign materials studied on the sign brightness. As can be seen, the buttons are brightest at greater distances but have a sharp peak and are less effective at closer distances. SIGNAL SILVER has the same type of characteristics but is not as bright as buttons at the large distances. waft silver scotchlite yields a lower brightness at the far distances but is flatter in the range from 800 ft down and is brighter than either buttons or SIGNaL SILVER below 100 ft . It should be noted that the standard roadside position ( $Y=20 \mathrm{ft}$ ) used in these calculations yields a low value of entrañee angles, as discussed earlier. All the following figures use waft SILVER SCOTCHLITE material for the sign legend.

Figure 18 shows the effect of different roadside sign positions for a straight road. As Figure 18 shows, at close range, the further the sign is from the traveled way the dimmer it appears to the driver. At longer distances, the effective change in brightness is negligible. The very substantial difference between high- and low-beam use on sign brightness is apparent.

Figure 19 shows the same road condition for three other sign positions. The curves show that the overhead sign in the right lane ( $Y=-6 \mathrm{ft}, Z=22 \mathrm{ft}$ ) is brighter than the signs located in the median or over the median lane. Once again, the major effect of headlamp beam use is apparent.

Figure 20 shows the brightness of the six sign positions when located on a road with a right horizontal curve with a degree of curvature $(D)$ of $1^{\circ}$ and a total change of direction ( $\Delta$ ) of $40^{\circ}$. Figure 21 shows the same six signs for a left horizontal curve for the same degree of curvature and deflection angle.

Figures 22 and 23 are families of curves representing different $D$ 's and $\Delta$ 's for a standard roadside sign for right and left curves, respectively. These curves show that the major factor affecting the brightness appears to be the total change in direction, and that brightness is affected only slightly by the degree of curvature.

Figures 24 and 25 are families of curves for the six sign locations for a sag and crest, respectively, with grade changes of 2 percent. Figure 26 shows the effect of grade changes on the brightness of a standard roadside sign. As the grade change becomes larger, brightness increases for
crest vertical curves and becomes smaller for sag vertical curves.

Figure 27 shows the effects for a straight road and a standard roadside sign. $t=1.0$ represents a perfect transmission medium, whereas $t=0.7$ is a value of attenuation per mile that represents an average day. As Figure 27 shows, the brightness changes are slight until the equivalent of a thin fog or haze ( $t=0.0019$ or $t=0.044$, respectively) is reached.

Figure 28 shows the variations of sign brightness caused by a change in the voltage from the nominal. As can be seen from the plot, a slight voltage change ( 13.0 volts) has a minor effect on sign brightness. As the voltage difference increases, the variations become more significant.

Figure 29 shows the effect of misaim of $1^{\circ}$ upward and $1^{\circ}$ downward from the nominal on the sign brightness for a straight, level road and a standard roadside sign. For these conditions, a misaim of $1^{\circ}$ upward causes the output to fall below the calculated vertical angle. Similarly, a misaim of $1^{\circ}$ below specifications (140) puts the distribution above the values calculated by $1^{\circ}$.

Figure 30 shows the effect of aging on sign material brightness. The two cases shown are for time periods of two years and six years.

Figure 31 show the brightness of the sign as seen by the driver of a car in the right lane for three separate illumination conditions: (1) from his own headlamps, (2) from the headlamps of a car in the second lane alongside his car, and (3) from the headlamps of a car in the second lane and five car lengths ahead of his car. The reduced brightness for conditions (2) and (3) are principally because of the relatively large divergence angles. No attempt was made to determine the relative use of high and low beams by the various cars.

The resulting brightness to the driver of a car in the right lane is cumulative, as shown by the curves in Figure 32.

## Field Validation of Computer Simulation

Description.-Brightness measurements were made on a SILVER SCOTCHLITE sign sample and on a diffuse reference target on an unused taxiway at the Peconic River Airport, Calverton, Long Island, N.Y. These field tests were performed to check the validity of the analytically derived values of brightness as determined by the computer program. This airport site was chosen because of the need for a long straight road without any interference from extraneous lights and for its accessibility to the researchers' offices.

Hoffman Engineering Corporation (Old Greenwich, Conn.) supplied the equipment and operator for the experimentation. A Pritchard photometer was used for the experiment because of its high sensitivity and capability of measuring extremely low levels of luminance. Figure 33 shows the photometer mounted in the test vehicle. The photometer and its internal brightness source were calibrated to a brightness standard traceable to the National Bureau of Standards on the morning preceding the experiments.

The photometer was mounted inside a 1967 Mercury


Figure 16. Sign brightness: car type.


Figure 18. Sign brightness: roadside sign positions.


Figure 17. Sign brightness: reflective material.


Figure 19. Sign brightness: overhead and median sign positions.


Figure 20. Sign brightness: right horizontal curveall sign positions.


Figure 22. Sign brightness: roadside position on right horizontal curve.


Figure 21. Sign brightness: left horizontal curve-all sign positions.


Figure 23. Sign brightness: roadside position on left horizontal curve.


Figure 24. Sign brightness: sag vertical curve-all sign positions.


Figure 26. Sign brightness: roadside position on vertical curves.


Figure 25. Sign brightness: crest vertical curve-all sign positions.


Figure 27. Sign brightness: transmissivity effects.


Figure 28. Sign brightness: voltage effects.


Figure 30. Sign brightness: aging effects.


Figure 29. Sign brightness: misaim effects.


Figure 31. Sign brightness: effects of additional cars on road.

Commuter station wagon. The position of the photometer was the same for all readings. Figure 34 shows the vehicle and the equipment situated inside it. The entrance pupil of the photometer was located at the position of the driver's eye $(7.9 \mathrm{ft}$ to the rear of the car headlamps, 1.4 ft toward the driver's side from the center of the car, and 3.95 ft above ground level). To prevent photometer shift because of the movement of the operator and other personnel within the car, the four corners of the car were jacked up just high enough to make the car springs inoperative. With the car in this position, the centers of the lamps were 28 in . above the ground, or 2 to 3 in . above their normal position. Before the tests the car's headlamps were aligned to SAE specifications.

The brightness of two objects was measured: (1) a Waft silver scotchlite sign sample, and (2) a diffuse reference target. The sample of the reflectorized material was first tested for its photometric properties by Electrical Testing Laboratories, N.Y. The specific luminance characteristics were then used in finding the brightness of that particular sample in relation to the amount of light at the sign.

The illumination of the sign position was determined by measuring the brightness of a diffuse reference target and converting that value of foot-lamberts to foot-candles by dividing by its reflectance. White Eastman Kodak blotting paper, with a diffuse reflectance of 80 percent, was used as a reference. Therefore, the foot-candle of light energy falling on the reference is determined by dividing the measured brightness(es) by the 0.8 reflectance factor of the reference target.
During the measurements, the reference and then the sign sample were mounted on the rear of a truck with their centers 12 ft above the ground. The reference and sign were both 4 by 4 ft in size; the locations of both with respect to the car are shown in Figure 35. The car was stationed with its direction parallel to the center line of the taxiway.


Figure 32. Sign brightness: total luminance with additional cars.

To eliminate photometer errors, the instrument was calibrated to its internal brightness source before and after each set of measurements. Because the ambient light on the reference was so low, the photometer had to be used at its greatest sensitivity to measure ambient light. For best possible accuracy, zero and dàrk current adjust-


Figure 33. Pritchard photometer.


Figure 34. Car set up for experimental brightness measurements.
ments were made before each reading. Readings were made at the following positions:

1. $1,000-\mathrm{ft}$ distance and $20-\mathrm{ft}$ offset.
2. $1,000-\mathrm{ft}$ distance and $60-\mathrm{ft}$ offset.
3. $400-\mathrm{ft}$ distance and $20-\mathrm{ft}$ offset.
4. $400-\mathrm{ft}$ distance and $60-\mathrm{ft}$ offset.

Measurements at the $1,000-\mathrm{ft}$ positions were made with a 6 -min aperture in the photometer so that the area measured was 1.70 ft in diameter. At the $400-\mathrm{ft}$ positions, a $15-\mathrm{min}$ aperture was used covering a field 1.76 ft in diameter. Brightness measurements represent the integrated foot-lamberts of the field area covered.

Two consecutive sets of readings were taken on the


Figure 35. Layout of testing positions.
reference and sign sample for each position with respect to the car. This was done to correct as much as possible the effects of changing atmospheric transmission, changing ambient light, and the possible change in light output from the car lamps. After each set of readings, the voltage at that headlamp was read. By doing this, a constant watch on the possible variations of the headlamp was noted.

Vertical board baffles, about 6 in . high, were placed at right angles to the light path on the pavement between the car and the sign-carrying truck, to determine whether reflected light from the pavement had any effect on the sign brightness. The effect of the baffles was less than that noted between two consecutive sets of readings; therefore, the baffles were discarded.

To check the attenuation of light because of a long path through the atmosphere and the windshield, the photometer was removed from the car and set up near the reference-carrying truck. Measurements were made with the photometer located about 20 ft from the reference at an angle of $45^{\circ}$ and focused on its center. The field covered with the photometer so located was about 2.5 in . in diameter. Because this test was done when the sky was extremely clear, no variations in brightness were measured by the additional length of light travel.

The brightness measured on the Kodak blotting paper reference, caused by ambient light, was from 0.0001 to 0.0002 foot-lambert at all four positions. The brightness at the photometer position caused by the reflectance of the ambient light by the silver scotchlite was about the same level as the diffuse reference at the 1,000 - ft positions. At the $400-\mathrm{ft}$ position, it increased to 0.0011 foot-lambert with the $60-\mathrm{ft}$ offset position, and 0.009 foot-lambert at the $20-\mathrm{ft}$ offset positions. For all positions at the reference (or sign), the ambient light brightness is so low compared to brightness measured from the car lamps that it can be considered negligible.

During all tests, the illuminated areas, car headlamps, and windshield were kept free of dew.

The readings, in foot-lamberts, were made for the headlamps separately by uncovering each headlamp, one at a
time, on both high and low beam. Readings were also made for no headlamps (ambient brightness) and for all headlamps operating together. Table 14 is an example of the test results recorded for a $1,000-\mathrm{ft}$ road distance and $20-\mathrm{ft}$ offset.

Table 15 gives all the results from each headlamp for the four test positions. The brightness column lists the theoretical and observed values of luminance. The theoretical value is determined as follows. Knowing the geometric relations of the car headlamp, the sign position, and the

TABLE 14
EXAMPLE OF TEST RESULTS

| Road distance $=1,000 \mathrm{ft}$ | Offset $=20 \mathrm{ft}$ |
| :--- | :--- |
| Photometer aperture $=6 \mathrm{~min}$ | Field coverage $=1.7 \mathrm{ft}$ (diameter) |

Time of measurement: 9:00 PM to 9:35 PM

| CAR LAMPS | FOot-lamberts |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | RIGHT |  | LEFT |  | ALL |
|  | Main | AUXILIARY | main | AUXILIARY |  |
| (a) Car lamps on high beam |  |  |  |  |  |
| Kodak blotting paper | 0.004 | 0.007 | 0.0035 | 0.0065 | 0.0222 |
|  | 0.004 | 0.008 | 0.004 | 0.0065 | 0.0220 |
| SILVER SCOTCHLITE | 0.900 | 1.88 | 1.01 | 1.67 | 5.40 |
|  | 0.880 | 1.82 | 1.00 | 1.60 | 5.20 |
| (b) Car lamps on low beam |  |  |  |  |  |
| Kodak blotting paper | 0.004 | - | 0.004 | - | 0.0075 |
|  | 0.004 | - | 0.004 | - | 0.0075 |
| SILVER SCOTCHLITE | 0.780 | - | 0.800 | - | 1.580 |
|  | 0.770 | - | 0.770 | - | 1.520 |

TABLE 15
FIELD TEST RESULTS

| position | road distance(FT) | $\begin{aligned} & \text { OFFSET } \\ & \text { (FT) } \end{aligned}$ | beam | brightness (footLAMBERTS) |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | THEORETICAL | OBSERVED |
| 1 | 1,000 | 20 | Right main | 1.59 | 0.89 |
|  |  |  | Right auxiliary high | 3.14 | 1.85 |
|  |  |  | Left main high | 1.65 | 1.01 |
|  |  |  | Left auxiliary high | 2.91 | 1.64 |
|  |  |  | Right main low | 1.61 | 0.78 |
|  |  |  | Right auxiliary low | 1.77 | 0.79 |
| 2 | 1,000 | 60 | Right main high | 1.57 | 0.68 |
|  |  |  | Left auxiliary high | 2.03 | 1.08 |
|  |  |  | Left main high | 1.23 | 0.62 |
|  |  |  | Left auxiliary high | 1.99 | 0.94 |
|  |  |  | Right main low | 1.61 | 0.92 |
|  |  |  | Left main low | 1.72 | 0.84 |
| 3 | 400 | 20 | Right main high | 5.62 | 3.35 |
|  |  |  | Right auxiliary high | 4.08 | 2.28 |
|  |  |  | Left main high | 6.19 | 3.53 |
|  |  |  | Left auxiliary high | 4.91 | 2.82 |
|  |  |  | Right main low | 1.34 | 0.75 |
|  |  |  | Left main low | 1.53 | 0.80 |
| 4 | 400 | 60 | Right main high | 1.45 | 0.87 |
|  |  |  | Right auxiliary high | 1.15 | 0.66 |
|  |  |  | Left main high | 1.23 | 0.71 |
|  |  |  | Left auxiliary high | 1.71 | 1.01 |
|  |  |  | Right main low | 3.20 | 1.75 |
|  |  |  | Left main low | 3.21 | 1.82 |

photometer position, the divergence and entrance angles are calculated. Using the reflectivity characteristics for the particular sample of sign material, the specific luminance (foot-lamberts per foot-candle) at that point is determined. Using the measured values of brightness of the diffuse reflector, the foot-candle of light energy falling at that point is then calculated (by dividing the footlambert reading by 0.8 ). The product of specific luminance and foot-candles is the theoretical value of brightness of the sample material. The observed values of brightness are the actual readings of luminance of the sample material as measured directly.

Discussion of Results.-The purpose of this analysis is to determine whether a direct relationship exists between observed and theoretical brightness, and, if so, what this relationship is.

The first step in the analysis was to determine the correlation between the two variables. Before proceeding, it must be noted that $r$, the coefficient of correlation, must not be thought of as something that proves causation. In fact, it indicates only that: (1) a variation in either variable may be caused, either directly or indirectly, by a variation in the other, (2) a common cause affects both variables, (3) the causal relationship is a result of interdependent relationships, or (4) it may be due to chance (152).

The data generated for the observed and theoretical values indicate the type of causal relationship present. Both values are directly related to the individual geometry of each measurement, and are dependent on such geometry. The calculated $r=0.91632$ indicates that the covariation of the two variables is due to a common cause affecting each variable in the same way. Therefore, a change in alignment geometry will cause a change in both variables, and the change will be highly correlated, or predictable.

Ratios of observed to theoretical values were computed. Of these ratios, 80 percent fall into the range from 0.46 to 0.60. Because the field of photometric measurements deals in orders of magnitude, as can be seen by the logarithmic representations of luminance, this correspondence between observed and theoretical values falls well within the range of normally accepted accuracy.

## Sign Design

Three major factors enter into the design of signs: legend, location, and size. The question of choice of legend falls outside the scope of this section; it is discussed elsewhere in this report. Location is determined largely by legend. Minor variations in location, where feasible, are considered later.

The purpose of this section is to consider the matter of sign size, or, to be more accurate, the question of letter size for night visibility. The primary determinants of sign panel size are the length of the sign message and the height, and series, of the letters. Letter size is determined by the need to have the sign message become first legible at a point determined by the reading time of the message and the geometry of the road and lateral sign location. The section on "Effects of Lateral Sign Displacement"
deals with this aspect. Letter size is selected on the basis of the visual acuity of the design driver under daylight conditions and then is checked for adequacy for nighttime illumination.

This checking procedure consists of combining the methods outlined previously for determining sign brightness with the correlation between brightness and legibility previously determined by Allen et al. (133) and shown in Figure 8. The two curves shown are for light legends on dark background and low ambient illumination. Allen et al. (133) include curves for other conditions.

For actual design purposes, each signing case should be handled individually using actual specific conditions (e.g., a rural condition with low ambient illumination, with headlight glare, and a light legend on a dark background).

Using the specific condition to compute legibility, as against the conditions of Figure 11, results in a change of less than one standard size * in computed letter height. Two exceptions to this rule are found in the cases of light legends on dark backgrounds for rural roads without headlight glare, where legibility is greater (smaller letters required) and for bright urban roads where legibility is much lower (larger letters required). The important fact to recognize is that the legibility factor (feet per inch letter height) decreases rapidly for signs when brightness falls below 20 foot-lamberts.

## Determination of Required Letter Height

The computed results for brightness as a function of the sign, road, and vehicle, empirical results of legibility versus brightness, and empirically derived relationships of sign legend and reading time can now be used to calculate the required minimum letter height.

Figure 36 shows the relationship of minimum letter height required to distance from the sign. This example represents the case of a straight road and a sign legend made from standard sheeting-type material such as is used on Interstate signs. The points used for plotting are obtained by first determining the brightness at the center of a 20 -ft-wide sign which is: (1) ground-mounted a standard distance off the edge of the highway at an elevation of 7 ft above the pavement, and (2) overhead-mounted and centered over the curb lane with the bottom 17 ft above the pavement. Legibility values are then determined for each value of brightness (Fig. 8). At each point the distance (feet) is divided by the legibility value (feet per inch) corresponding to the brightness at that point. The quotient (inches) is then plotted on the graph corresponding to the distance at which it is calculated. For reference and comparative purposes, the commonly used rule of thumb, 50 ft of legibility per inch of letter height, is also plotted.

Figure 36 shows only one high-beam curve. This is because the brightness values at a high level are past the knee of the legibility curve (Fig. 8). Small variations in brightness do not yield significant changes in legibility.

[^17]Therefore, the letter heights are equivalent for the highbeam case.

These curves show the relationship between the minimum letter height required to transmit the message and the distance at which the message is to be legible. For example, if the sign being studied is to be read at 700 ft , for a car using low beams, the letter height of the roadside sign must be at least 17 in ., and the overhead sign must have letter heights of at least 22 in . If the road situation allows for high-beam traffic, the minimum letter height would be 11 in . The design engineer would then select the next highest standard letter size for that sign. The total sign size is then determined using standard sign design procedures.

Although vehicles are equipped with both high- and low-beam headlight systems, indications are that most vehicles are operated at night using low beams. This is true even for relatively low-volume, rural, Interstate, di-vided-highway alignments. A study in South Dakota (154) reported that 67 percent of all motorists traveling the Interstate Study Section were using their low beams when first sighted. A later study (141) done throughout the United States on both two- and four-lane roads indicated that, for a sample of more than 23,000 vehicles observed under open-road conditions, less than 25 percent were using high beams.

Therefore, for the purpose of designing reflectorized signs, low-beam operations must be assumed to predominate. One reservation to this statement should be kept in mind. The nationwide study stated that "There are marked variations in beam usage habits of drivers from area to area in the United States." The designer must thus keep local conditions in mind before deciding on a "design beam."

If the computed over-all sign dimensions differ appreciably from the values assumed at the beginning of the computation, the new values are used in an iterative process until agreement is reached.

## Sign Design

These computations will result in a sign design with a letter height, for the given conditions, that will yield the required legibility at the required distance. The sign design must then be checked against the constraints placed on it. For example, checks should be made to determine whether: (1) the sign will fit in the position allotted to it, and (2) it blocks or is blocked by obstructions on the highway. If these criteria are met, a check is made to see whether the sign itself poses any problems.
The first question is, "Are the letters too big and unwieldly to use?" When the required letter height exceeds 30 in., commercial availability and other economic considerations assume great importance. Alternative locations for the sign, which might have better brightness characteristics or fixed illumination of the sign, should be considered. Increased brightness will reduce the required letter size. If these alternatives prove impractical due to economic or other considerations, other aiding techniques must be investigated.


Figure 36. Minimum required letter height as a function of required reading distance.

All of these expedients fall within the premise of transmitting the message originally selected. The determinants of reading distance are speed and reading time (130). Reading time is a function of message length and message complexity. A change in the message may thus have the effect of reducing reading distance, bringing the point of first legibility closer to the sign location and, therefore, reducing required minimum letter height.

An additional point that should be mentioned is whether the legibility data described by Allen et al. (133) are valid for drivers with impaired vision. The median driver has a visual acuity of $20 / 20$, which is the same as that of the observers used in Allen's study. Therefore, using Allen's results to satisfy legibility requirements implies satisfaction for at least 50 percent of the drivers on the road. If a greater percentage is to be included, drivers with lower visual acuities must be considered. The fifth percentile driver has a visual acuity of $20 / 70$. Owing to the lack of empirical results (like those of Allen) for drivers with impaired vision, the effect of reduced acuity on visibility distances can only be simulated from a consideration of the geometry of visual angles used in the definition of visual acuity.* On this basis, the 20/70 driver requires letter heights that are 3.5 times that of the median driver. Therefore, for the example used before, the ground-mounted sign would require letter heights of 59.5 in ., and the overhead sign would require letter heights of 77 in . for the low-beam case. These values, even though extremely large,** would still not satisfy 100 percent of the driving population.

It should be recognized that this procedure for sign design deals with only one of the variables involved: letter size to obtain required legibility. Other variables, such as location and message, are covered only insofar as they affect, or are affected by, the principal variable covered.

[^18]In discussing the adequacy of a given sign for night visibility conditions, another important variable must be considered. This is target value or sign visibility. The driver must devote his attention to the sign that he is to read before he can begin to read it (i.e., he must select this particular signal source over all the other signal sources competing for his attention at the particular moment). The lead time required between the last point at which the sign should be detected and the point of beginning legibility cannot be determined unequivocally. It depends on the complexity of the task to which the driver is attending and on the number of competing sources. A qualitative evaluation must be made for every individual location and the proposed sign design must be checked for adequacy of target value. This particular area has been studied extensively at Michigan State University. A recent paper by Forbes et al. (155) gives a suggested procedure for predicting sign visibility that can be used for this evaluation.

## Effect of Sign Position

When a trial sign positions results in insufficient brightness the design engineer can check to determine if another possible sign position will yield higher legibility values. Figure 37 shows the letter height versus visibility curve for each of six possible sign positions for a straight road. The sign is 20 ft wide and 10 ft high, with the legend made from reflective sheeting material. The $20-\mathrm{ft}$ offset sign is the standard ground-mounted sign. The 40- and $60-\mathrm{ft}$ offset signs represent signs displaced from the highway by 30 and 50 ft , respectively. The curb-lane overhead sign is the standard, and the median-lane overhead sign is mounted over the fourth lane, of an eight-lane divided highway, with the bottom of the sign 17 ft above the pavement. The median sign is placed to the left of the median lane, with the bottom of the sign 7 ft above the pavement.

It can easily be seen that these signs require letter heights that exceed the limits of practicality, if the sign is designed to be illuminated by headlights alone. Fixed, internal or external illumination of the signs will reduce the required letter heights. If, for the example previously


Figure 37. Effect of sign position on letter height.
given, the overhead sign were artificially illuminated to a value of 20 foot-lamberts, the letter height required to place the point of first legibility 700 ft upstream of the sign would be 12.5 in . (according to the data in Fig. 8). Once again, these numerical values are for a median driverwith $20 / 20$ vision.

There are additional effects of reduced brightness due to badly aimed headlights, changes in voltage in the lighting circuits, aging of sign material, and transmissivity (attenuation through the atmosphere). The effect of these factors must be considered on an individual basis.

## Effect of Alignment

Figure 38 shows some of the effects of horizontal curvature on the brightness of signs. The plots are for a road curving to the right and show the effect of degree of curvature, $D$, and deflection angle, $\Delta$, as a standard four-door sedan is driven toward the sign. The graphs for the left curvature are similar in shape but show slightly greater letter-height requirements.

Figure 39 shows letter heights required to transmit the message to a driver with the sign offset 30 ft from the highway for a highway with vertical alignment changes. The sign, like the one on the road with horizontal curvature, is located at the end of the curve. Results are shown for two values of total grade change for both crest and sag curves. In each case, the recommended (21) minimum length of curve for a design speed of 70 mph was used in the calculations. As the curvature becomes greater, the letter-height requirements, for the sag curve, are increased, while the letter heights required for a crest curve decrease as the grade change increases.

## Application of Computer Program

The sign brightness computer program, described in Appendix C, was applied to existing signs along a stretch of I-85 in North Carolina. The test site is described in Appendix B.

The road in question is a modern Interstate' highway running in a general east-west direction. For purposes of this analysis an 18 -mile section of the eastbound roadway was selected. The original sign plans were obtained and


Figure 38. Effect of changes in approach horizontal alignt ment on letter height.
field-checked. At the time of the field check, 94 signs were noted. Their distribution by type is given in Table 16. This table also gives the number, and type, of signs selected for analysis. The signs selected for analysis were generally those contained in the original sign plans and found at the same location at the time of the field check.

A total of 63 signs were analyzed. Input data for the program were prepared from the construction plans, the signing plans, and the North Carolina signing specifications (157). The sign material characteristics used were those for Waft silver scotchlite after five years or more exposure, as supplied by the manufacturer.

Prior to the analysis the entire section was inspected, under both night and day conditions, by an experienced traffic engineer. In his judgment the existing signing, as a whole, came well up to accepted Interstate standards. The major criticism was that the classification of some of the interchanges as minor or intermediate, as inferred from the number and location of advance guide signs, was open to question and that some of these could equally well have been signed as intermediate or major, respectively.
Night inspection of the roadway revealed that some of the demountable copy had deteriorated considerably and had lost a considerable proportion of its reflectivity. Because actual testing of the material proved not to be feasible, the computed results, using the manufacturersupplied photometric properties of aged scotchlite, are probably on the high side.

## Results of Computer Analysis

The results of the computer analysis are given in Table 17. This table gives the sign number (arbitrarily assigned by the researchers to identify computer output), the type of sign, the type of mounting, and the existing letter height for various types of copy. These data were taken from the original signing plans. The following code is used to identify sign type:

| ED | Exit direction |
| :---: | :---: |
| EX | Fxit |
| MT | Merging traffic |
| TT | Through traffic |
| CR | Confirmatory route marker assembly |
| SL | Speed limit |
| DD. | Destination and distance |
| AG. | Advance guide |
| RL | Right lane |
| SG | Supplementary guide |
| GR. | . Ground-mounted |
| OH. | Overhead-mounted |

When more than one value is shown for letter size, different lines in the sign had different letter heights specified.

The required legibility distance for each sign was computed and entered on the table. This is the distance at which a sign must become legible in order for the reading to be completed before the sign passes outside the cone of normal vision. The procedure used in computing this distance was first developed by Mitchell and Forbes (130)


Figure 39. Effect of changes in approach vertical alignment on letter height.

TABLE 16
SIGNS ON I-85

| SIGN TYPE | ANALYZED | NOT <br> ANALYZED | TOTAL |
| :---: | :---: | :---: | :---: |
| Regulatory: |  |  |  |
| DO NOT LITTER | 0 | 3 | 3 |
| Speed limit | 3 | 4 | 7 |
| Reduce speed ahead | 0 | 1 | 1 |
| Warning: |  |  |  |
| MERGING TRAFFIC | 14 | 0 | 14 |
| ICE ON BRIDGE ${ }^{\text {a }}$ | 0 | 11 | 11 |
| LOW CLEARANCE ${ }^{\text {b }}$ | 0 | 2 | 2 |
| Guide: |  |  |  |
| Advance guide | 13 | 1 | 14 |
| Exit direction | 13 | 0 | 13 |
| Exit | 13 | 0 | 13 |
| D \& D | 2 | 0 | 2 |
| Supplementary exit | 0 | 1 | 1 |
| Confirmatory route marker ${ }^{\text {e }}$ | 5 | 0 | 5 |
| Miscellaneous ${ }^{\text {d }}$ | 0 | 8 | 8 |

${ }^{2}$ Folding signs, observed in closed position.
${ }^{6}$ Opposite mounted at one location.
c One location with three shields.
${ }^{2}$ Includes cross road identification and city-limit signs.
and is detailed in Chapter Four. The Road Research Laboratory formula (99) was used to compute reading time.

The next six columns of Table 17 give the results of the computer simulation. Apparent brightness of a sign to an observer located 400,600 , and 800 ft away, for both high- and low-beam illumination, was taken from the computer run. The figure shown is the value computed for the center of the sign.

The last three columns indicate the computed required minimum letter height. Three separate values are shown. The first is daytime letter height obtained by applying the 50 -ft-per-inch rule to the required legibility distance. The other two represent minimum letter heights for night-

TABLE 17
EXISTING AND REQUIRED LETTER SIZE

| SIGN NO. | TYPE | TYPE OF MOUNTING | EXISTING LETTER SIZE |  |  |  |  | REQUIRED <br> Legibility <br> distance <br> (FT) | APPARENT BRIGHTNESS |  |  |  |  |  | REQUIRED LETTER HEIGHT |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | NUMER- | NUMER- <br> ALS <br> IN |  | 400 FT |  | 600 FT |  | 800 FT |  | $\begin{aligned} & \text { DAY ( } 50 \\ & \text { FT/IN.) } \end{aligned}$ | HIGH <br> BEAM | LOW <br> BEAM |
|  |  |  | U.C. | L.C. | CAPS | ALS | SHIELD |  | HIGH | LOW | HIGH | Low | HIGH | Low |  |  |  |
| 1 | ED | GR | 16 | 12 |  |  |  | 460 | 6.90 ! | 0.96 | 9.77 | 0.89 | 8.19 | 0.71 | 10 | 12 | 10 |
| 2 | EX | GR |  |  | 12 |  |  | 410 | 3.22 | 0.48 | 1.93 | 0.27 | 1.07 | 0.17 | 10 | 10 | 10 |
| 3 | MT | GR |  |  | 8 |  |  | 460 | 11.53 | 2.04 | 12.56 | 3.65 | 8.21 | 4.90 | 10 | 10 | 8 |
| 4 | EX | OH |  |  |  |  | 12 | 490 | 4.69 | 0.24 | 5.28 | 0.18 | 4.25 | 0.14 | 10 | 12 | 13.33 |
| 5 | TT | OH | 16 | 12 |  |  | 12 | 540 | 6.50 | 0.26 | 6.15 | 0.20 | 4.95 | 0.17 | 12 | 12 | 16 |
| 6 | CR | GR |  |  | 7 |  | 12 | 430 | 8.73 | 0.95 | 10.46 | 0.86 | 8.52 | 0.63 | 10 | 10 | 10 |
| 7 | SL | GR |  |  | 8 | 16 |  | 430 | 3.20 | 0.47 | 3.65 | 0.31 | 4.44 | 0.31 | 10 | 10 | 12 |
| 8 | DD | GR | 13.33 | 10 |  | 13.33 |  | 600 | 3.79 | 0.64 | 3.03 | 0.53 | 2.15 | 0.40 | 12 | 13.33 | 16 |
| 9 | AG | GR | 16 | 12 | 10 | 15 |  | 630 | 4.95 | 0.70 | 7.64 | 0.75 | 7.34 | 0.61 | 13.33 | 13.33 | 16 |
| 10 | ED | GR | 16 | 12 |  |  |  | 570 | 4.17 | 0.68 | 4.08 | 0.63 | 3.55 | 0.54 | 12 | 13.33 | 13.33 |
| 11 | EX | GR |  |  | 12 |  |  | 410 | 7.44 | 0.86 | 9.46 | 0.82 | 6.66 | 0.62 | 10 | 10 | 10 |
| 12 | MT | GR |  |  | 8 |  |  | 460 | 8.29 | 0.93 | 10.01 | 0.85 | 6.92 | 0.64 | 10 | 10 | 10 |
| 13 | CR | GR |  |  | 7 |  | 12 | 430 | 15.69 | 0.72 | 7.65 | 0.25 | 2.05 | 0.10 | 10 | 10 | 10 |
| 14 | AG | GR | 16 | 12 | 10 | 15 | 12 | 690 | 15.34 | 0.87 | 13.45 | 0.47 | 3.21 | 0.37 | 16 | 16 | 18 |
| 15 | ED | GR | 16 | 12 |  |  | 12 | 630 | 4.32 | 0.56 | 6.90 | 0.57 | 6.42 | 0.49 | 13.33 | 13.33 | 16 |
| 16 | EX | GR |  |  | 12 |  |  | 410 | 2.65 | 0.37 | 1.33 | 0.21 | 0.69 | 0.12 | 10 | 10 | 12 |
| 17 | MT | GR |  |  | 8 |  |  | 460 | 3.35 | 0.56 | 1.98 | 0.38 | 1.02 | 0.17 | 10 | 12 | 12 |
| 18 | MT | GR |  |  | 8 |  |  | 460 | 3.36 | 0.56 | 1.98 | 0.38 | 1.32 | 0.25 | 10 | 12 | 12 |
| 19 | CR | GR |  |  | 7 |  | 12 | 430 | 8.20 | 0.89 | 9.72 | 0.81 | 6.95 | 0.50 | 10 | 10 | 10 |
| 20 | SL | GR |  |  | 8 | 16 |  | 430 | 10.62 | 1.41 | 13.32 | 1.91 | 9.64 | 2.91 | 10 | 10 | 10 |
| 21 | DD | GR | 13.33 | 10 |  | 13.33 |  | 610 | 5.44 | 0.71 | 8.17 | 0.73 | 7.34 | 0.58 | 13.33 | 13.33 | 13.33 |
| 22 | AG | GR | 16 | 12 | 10 | 16/15 |  | 690 | 10.46 | 0.84 | 8.40 | 0.57 | 4.16 | 0.22 | 16 | 16 | 18 |
| 23 | ED | GR | 16 | 12 | 16 | 16 |  | 630 | 5.64 | 0.72 | 8.63 | 0.77 | 8.77 | 0.97 | 13.33 | 13.33 | 16 |
| 24 | EX | GR |  |  | 12 |  |  | 410 | 7.57 | 0.87 | 9.84 | 0.83 | 8.20 | 0.62 | 10 | 10 | 10 |
| 25 | MT | GR |  |  | 8 |  |  | 460 | 8.46 | 0.95 | 10.40 | 0.86 | 8.48 | 0.64 | 10 | 10 | 10 |
| 26 | CR | GR |  |  | 7 |  | 12 | 430 | 8.03 | 0.86 | 9.81 | 0.80 | 8.18 | 0.60 | 10 | 10 | 10 |
| 27 | SL | GR |  |  | 8 | 16 |  | 430 | 7.68 | 0.85 | 9.50 | 0.80 | 6.19 | 0.43 | 10 | 10 | 10 |
| 28 | AG | GR | 16 | 12 | 16/12/10 | 16/15 |  | 800 | 4.46 | 0.64 | 6.52 | 0.63 | 6.04 | 0.49 | 16 | . 18 | 24 |
| 29 | MT | GR |  |  | 8 |  |  | 460 | 5.52 | 0.68 | 3.33 | 0.46 | 2.07 | 0.35 | 10 | 10 | 12 |
| 30 | EX | OH | 16 | 12 | 16/12 | 16 |  | 590 | 5.95 | 0.26 | 5.74 | 0.32 | 3.21 | 0.30 | 12 | 13.33 | 16 |
| 31 | TT | OH | 16 | 12 | 12 |  | 12 | 510 | 2.37 | 0.18 | 5.22 | 0.18 | 4.98 | 0.30 | 12 | 12 | - |
| 32 | AG | GR | 16 | 12 | 10 | 15 |  | 590 | 6.49 | 0.96 | 9.47 | 0.90 | 8.04 | 0.72 | 12 | 12 | 13.33 |
| 33 | MT | GR |  |  | 8 |  |  | 440 | 16.40 | 0.87 | 9.88 | 0.31 | 4.53 | 0.28 | 10 | 10 | 12 |
| 34 | MT | GR |  |  | 8 |  |  | 440 | 15.53 | 0.64 | 6.66 | 0.25 | 1.98 | 0.10 | 10 | 10 | 10 |
| 35 | ED | GR | 16 | 12 | 10 |  |  | 560 | 11.67 | 0.68 | 5.49 | 0.18 | 1.49 | 0.08 | 12 | 12 | 16 |
| 36 | ED | GR | 16 | 12 |  |  |  | 530 | 5.35 | 0.73 | 8.07 | 0.77 | 7.51 | 0.61 | 12 | 12 | 12 |
| 37 | EX | GR |  |  | 12 |  |  | 400 | 6.11 | 1.17 | 8.31 | 2.36 | 7.90 | 2.73 | 8 | 10 | 10 |
| 38 | MT | GR |  |  | 8 |  |  | 440 | 1.67 | 0.30 | 1.47 | 0.25 | 1.17 | 0.27 | 10 | 12 | 12 |
| 39 | RL | GR | 16 | 12 | 10 |  |  | 480 | 6.27 | 0.80 | 8.82 | 0.80 | 7.86 | 0.62 | 10 | 10 | 12 |
| 40 | ED | GR | 16 | 12 |  |  |  | 450 | 6.16 | 0.78 | 8.68 | 0.78 | 7.78 | 0.61 | 10 | 10 | 10 |
| 41 | EX | GR |  |  | 12 |  |  | 400 | 7.31 | 0.84 | 9.44 | 0.81 | 8.15 | 0.62 | 8 | 10 | 10 |
| 42 | MT | GR |  |  | 8 |  |  | 440 | 8.16 | 0.91 | 10.21 | 0.84 | 8.42 | 0.64 | 10 | 10 | 10 |
| 43 | T.T | GR | 16 | 12 | 15/10 | 15 | 15 | 740 | 6.20 | 0.82 | 10.73 | 1.24 | 9.17 | 1.75 | 16 | 16 | 16 |
| 44 | ED | GR | 16 | 12 | 10 |  |  | 520 | 21.98 | 1.37 | 16.88 | 0.54 | 11.43 | 0.46 | 12 | 12 | 12 |
| 45 | EX | OH | 16 | 12 |  |  |  | 490 | 5.26 | 0.25 | 3.64 | 0.15 | 2.38 | 0.10 | 10 | 12 | 13.33 |
| 46 | ED | OH | 16 | 12 | 15/10 | 15 | 15 | 650 | 4.71 | 0.39 | 3.44 | 0.19 | 2.35 | 0.11 | 13.33 | 16 | - |
| 47 | EX | OH |  |  | 7 |  | 15 | 680 | 2.85 | 0.38 | 2.99 | 0.25 | 2.41 | 0.16 | 16 | 16 | 20 |
| 48 | MT | GR |  |  | 8 |  |  | 440 | 8.41 | 0.96 | 9.25 | 0.75 | 4.79 | 0.31 | 10 | 10 | 10 |





time use for both high- and low-beam illumination. These values were obtained by converting luminance into unit reading distance using the data shown in Figure 8. For high beams the curve "with headlight glare" was used; for low beams, the curve "without headlight glare" controlled. The luminance value used was obtained by straight-line interpolation for the required reading distance from the computer results. The letter heights, computed by dividing required reading distance, are shown to the next highest "standard" size, which is assumed to be an even multiple of 2 in . except that 13.33 in . is used instead of 14 in .

## Discussion of Results

Comparison of the computed letter size requirements with the letter sizes actually required was made in terms of standard letter sizes. Table 18 gives the statistical distribution of this comparison. Two separate comparisons were made-one for all signs analyzed and one for guide signs (exclusive of confirmatory route markers) only. Forty-one signs fell into this latter category.

The "actual" size used in the comparison was the largest size letter on the sign. In cases where lower-case lettering was used in the largest size line, the height of the lowercase letter governed. It should be noted that considerable differences are encountered when the smaller "subsidiary" copy is examined. This includes such items as the cardinal direction for route markers, the exit message in advance

TABLE 18
DISTRIBUTION OF LETTER SIZE DEFICIENCIES

## LETTER

| SIZE | DAY |  | HIGH BEAM |  | LOW BEAM |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| FICIENCY | \% | CUMUL. | \% | CUMUL. | \% | CUMUL. |

(a) ALL SIGNS

| +4 | 3.2 | 3.2 | - | - | - | - |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| +3 | 4.8 | 8.0 | 6.3 | 6.3 | 3.2 | 3.2 |
| +2 | 3.2 | 11.2 | 1.6 | 7.9 | 7.9 | 11.1 |
| +1 | 34.9 | 46.1 | 33.3 | 41.2 | 27.0 | 38.1 |
| 0 | 27.0 | 73.1 | 23.8 | 65.0 | 12.7 | 50.8 |
| -1 | 19.0 | 92.1 | 19.0 | 84.0 | 14.3 | 65.1 |
| -2 | 7.9 | 100.0 | 14.3 | 98.3 | 17.4 | 82.5 |
| -3 |  |  | 1.6 | 100.0 | 7.9 | 90.4 |
| -4 |  |  |  |  | - | - |
| -5 |  |  |  |  | 1.6 | 92.0 |
| $\infty$ |  |  |  |  | 7.9 | 100.0 |


| (b) GUIDE SIGNS |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| +4 | 4.9 | 4.9 | - | - | - | - |
| +3 | - | 4.9 | 2.4 | 2.4 | - | - |
| +2 | 4.9 | 9.8 | - | 2.4 | 2.4 | 2.4 |
| +1 | 21.9 | 31.7 | 19.5 | 21.9 | 17.2 | 19.6 |
| 0 | 39.1 | 70.8 | 34.2 | 56.1 | 17.2 | 36.8 |
| -1 | 17.2 | 88.0 | 21.9 | 78.0 | 14.6 | 51.4 |
| -2 | 12.2 | 100.0 | 19.5 | 97.5 | 21.9 | 73.3 |
| -3 |  |  | 2.4 | 100.0 | 12.2 | 85.5 |
| -4 |  |  |  |  | - | 85.5 |
| -5 |  |  |  |  | 2.4 | 87.9 |
| $\infty$ |  |  |  |  | 12.2 | 100.0 |

guide or exit direction signs, and all other copy that requires smaller letter sizes in accordance with the Manual (93).

Table 18, shown graphically in Figure 40, shows a considerable degradation of performance when the illuminating medium goes from daylight through high beam to low beam. The cumulative distributions (plotted, for the two cases considered, in Figs. 41 and 42) show that 73 percent of all signs are adequate for daylight illumination, 65 percent for high beam, and 51 percent for low beam. If an allowance of one standard size is made, these figures are increased to 92 percent, 84 percent, and 65 percent, respectively.

When guide signs are considered alone, the situation is much more serious. The comparative figures for complete adequacy are 71 percent, 56 percent, and 37 percent, respectively. With the tolerance of one standard size these figures are increased to 88 percent, 78 percent, and 51 percent, respectively. Although several instances were noted where low-beam requirements were equal to, or even smaller, than those for the other two conditions investigated, the over-all impact of these figures must be that low-beam illumination appears to be inadequate for signs designed under current standards. The important fact to be noted is that five of the 13 overhead-mounted signs were completely illegible under low-beam illumina-tion-that is, the computed brightness at the point of required first legibility was less than 0.2 foot-lambert, the lowest value for which legibility data are available. Seven of the eight overhead signs for which legibility could be computed were found to require letters two or more
standard sizes higher than that required for daytime conditions.

One additional point should be made concerning the computations for overhead signs. Each sign was analyzed individually-that is, the reading time was computed on the basis of the message on that sign alone. A strong case can be made, however, for considering an overhead sign assembly, sign bridge or butterfly, as a single message, to be read in its entirety by the approaching driver. In that case the reading time would be considerably longer, the required legibility distance would be increased considerably, and the required letter sizes would be correspondingly larger.

Table 19 represents the computation of minimum letter size under the assumption that each of the overhead assemblies is considered as a single sign. The brightness values used were the average for the signs making up the assembly; otherwise, the computations are as described previously.

The increase in minimum required letter sizes is immediately apparent, amounting to at least two standard sizes for all conditions investigated. It can also be seen that three of the five assemblies are illegible under lowbeam illumination and the remaining two can be made legible only by using letter sizes that approach the limits of practical feasibility. In this connection it should be mentioned that the analysis was made using constant sign panel sizes. The increase in panel size necessitated by the increase in letter size would result in lower luminance, due to higher deflection angles, as well as increased required legibility distance, due to moving the last reading point


Figure 40. Distribution of letter size deficiencies.


Figure 41. Cumulative distribution, letter size deficiencies, all signs.


Figure 42. Cumulative distribution, letter size deficiences, guide signs only.
upstream. Both of these conditions would, in turn, result in still larger letter sizes.

It is also worth noting that all of the analyses were made using luminance values computed for the center of the sign. Examination of a typical computer output sheet (Fig. 43) shows that some variance exists between values for the center and values for the extremities. If worst-case, instead of average, luminance had been used in the calculations, still higher computed letter heights would have been obtained.

The data and the computed results of Table 17 show the considerable variation that exists for apparently identical signs. For instance, all 14 merging traffic signs analyzed required $10-\mathrm{in}$. letters for daytime conditions. However, when they were analyzed for nighttime conditions using low-beam illumination the analysis showed one location that required an 8 -in. letter, eight locations that required $10-\mathrm{in}$. letters, and five locations that required $12-\mathrm{in}$. letters. The variance increases as sign size increases. Signs 55 and 59 are identical, overhead-mounted, $9-\mathrm{ft}$ by $12-\mathrm{ft}$ signs with the legend through traffic. However, analysis shows a difference of two standard sizes in the high-beam case and a difference between "legible" and "illegible" in the low-beam case.

This great variance is due to enormous influence that apparently minor changes in horizontal and vertical alignment, especially the latter, have on the distribution of headlight illumination reaching the signs and on the resulting luminance. Figures 44 through 49 are plots of luminance versus distance from the signs for six signs used in the analysis. At the bottom of each sign the approach horizontal and vertical alignment is shown. Absence of horizontal alignment information indicates a tangent section.

Worthy of note are the dip in the luminance curves at 900 ft , at the beginning of the horizontal curve and on the downgrade, shown in Figure 44, contrasted with the smooth curve of Figure 45 which has no alignment changes but does have a continuous downgrade throughout the entire approach. Figure 46 shows a discontinuity in the low-beam curve in the area of combined vertical and horizontal alignment changes. However, these changes are not severe enough to affect the high-beam curve. Figure 47 shows an extremely sharp peak due to a horizontal curve to the left, with the sign at the beginning of the subsequent upgrade tangent section. Figure 48 shows a fairly steady alignment. It is interesting to compare this with Figure 45, noting the difference between the relative positions and magnitudes of the peaks of the high-beam and low-beam curves on each figure. Figure 49 shows the effect of extreme changes in vertical alignment, extreme by Interstate design standards, on the approaches to a sign.

## Conclusions

This case study in applying the computer simulation program to determine requisite letter size of signs for adequate nighttime visibility demonstrates the versatility of this simulation program as a tool for the optimum design of

TABLE 19
OVERHEAD SIGNS

| ASSEMBLY | SIGNS | REQ. LEGIB. DIST. (FT) | REQUIRED LETTER <br> HEIGHT ( $50 \mathrm{FT} / \mathrm{IN}$.) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | DAY | $\begin{aligned} & \text { HIGH } \\ & \text { BEAM } \end{aligned}$ | LOW <br> BEAM |
| A | 4,5 | 634 | 13.33 | 13.33 | - |
| B | 30,31 | 704 | 16 | 16 | 20 |
| C | 45,46,47 | 933 | 20 | 24 |  |
| D | 53,54,55 | 834 | 18 | 18 | 22 |
| E | 57,58,59 | 800 | 16 | 18 | - |

signs. The wide variations in results noted point up the necessity of designing each sign for the exact conditions and locations for which it will be used. Finally, the great variation noted between a sign design for high-beam use and one for low-beam use (which would have been even higher if the assumption of no headlight glare had been made) underlines the need to determine the prevailing headlight use. Because the two studies on headlight use (141, 154) indicate that reliance should not be placed on high-beam illumination, and because the results of these computations show the inadequacy of relying on low-beam illumination for overhead-mounted signs, it must be concluded that overhead signs require fixed illumination if they are to serve their purposes properly and effectively.

It should be emphasized that this section of highway analyzed is signed well in accord with the current manual requirements. Furthermore, comparison of actual field conditions with the signing plans indicates that every effort has been made to correct deficiencies in signing that have become apparent since the opening of the highway. The deficiencies that are revealed by the present analysis are not, therefore, attributable in any way to the North Carolina Highway Department; similar, or worse, results undoubtedly could have been obtained in any other jurisdiction, especially those that still use nonreflectorized sign backgrounds. These deficiencies are deficiencies in the present state of the art of sign design for night legibility as reflected in current manuals and design procedures.

## blockage of signs by trucks

The efficiency of signs as information systems depends on the degree to which the transmitted information is received. Any factor that can obscure or block the line of sight thus becomes extremely important and worthy of close scrutiny. For this reason, a theoretical mathematical analysis of the blockage of signs by trucks was made. Although it was undertaken primarily for the determination of the effects on signs, the analysis is equally applicable to any information source that depends on straightline transmission of either information or actuating signals for in-vehicle displays. Any transmission using infrared, microwaves, or lasers would fall into this classification.

The geometry of the blockage problem can be defined in terms of the lines of sight determined by the extremities of the sign and the extremities of the truck as viewed


Figure 43. Typical computer output-sign luminance.


Figure 44. Luminance versus distance-Sign 2.


Figure 45. Luminance versus distance-Sign 15.


Figure 46. Luminance versus distance-Sign 17.


Figure 47. Luminance versus distance-Sign 35.


Figure 48. Luminance versus distance-Sign 43.


Figure 49. Luminance versus distance-Sign 53.


Figure 50. Geometry of blockage problem.
from the sign. In Figure 50, let $D$ and $A$ represent the inner and outer edges, respectively, of the sign (as seen from above) and let $B$ and $E$ represent the left front and right rear extremities, respectively, of the truck at a given instant. The lines of sight $A B$ and $D E$ extended behind the truck define its "shadow." A driver will, by definition, have his vision of the sign blocked at a given instant if and only if the origin of his line of sight falls within this shadow at that instant. The shape and speed of this shadow is a function of truck speed, truck size, and position and size of the sign. Lane widths, road lengths, position of driver's line of sight, and car speed are other factors related to the geometry of the problem.

The initial task is to derive equations representing the boundaries of the truck's shadow as a function of time, $t$. Cars are then introduced in a specified lane at any time, $t_{s}$, and for each lane percentage blockages are calculated. For this calculation, it is necessary to make some assumptions on car and truck distributions. For this discussion, it is assumed for simplicity of analysis that cars enter the road segment in question randomly with respect to truck arrivals. It is then possible to calculate the probability, $P$, that a driver's vision of the sign will be blocked for at least ( $p \times 100$ ) percent of his time passage on the road segment. This is done for the case of one truck in the right-hand lane and any car that enters the road segment
during the time of truck passage, and similarly for two trucks in the right-hand lane. The resulting probabilities of blockage are tabulated by cases, and the one- and two-truck cases are compared.

In the following discussion, a four-lane highway is considered, and the lanes are denoted $1,2,3,4$, starting from the extreme right-hand lane. For each lane, a vehicular speed, which is a function of lane volume, will be assumed.

## Single Truck-Horizontal Blockage

## Description of Shadow

Let $x_{d}$ represent the maximum distance from which the sign may be seen, in which $x_{d}$ is measured perpendicular to the plane of the sign. Assume a straight section of road and consider a rectangular coordinate system in the plane of the road (Fig. 50). Let the $x$ axis be parallel to the road and pass through the outer edge, $A$, of the sign. Let the $y$ axis, which is perpendicular to the road, be at a distance, $x_{d}$, from $A$. Note that the time axis corresponds to the $x$ axis in the following manner: $t=0$ when the right rear extremity at the truck has its $x$ coordinate equal to zero (the initial position of the truck).

$$
\begin{aligned}
\text { At } t=0, & \\
A B: & {\left[\left(x_{d}, 0\right),\left(x_{12}, y_{12}\right)\right] } \\
D E: & {\left[\left(x_{d}, y_{d}\right),\left(0, y_{11}\right)\right] }
\end{aligned}
$$

At time $t$,

$$
\begin{array}{ll}
A B: & {\left[\left(x_{d}, 0\right),\left(x_{12}+v_{T} t, y_{12}\right)\right]} \\
D E: & {\left[\left(x_{d}, y_{d}\right),\left(v_{T} t, y_{11}\right)\right]}
\end{array}
$$

in which $v_{T}$ is the truck velocity.
The equations of the lines at time $t$ are:

$$
\begin{align*}
& A B: x=\frac{y}{y_{12}}\left(x_{12}+v_{T} t-x_{d}\right)+x_{d}=f_{1}(y)  \tag{2}\\
& D E: x=\frac{y-y_{d}}{y_{11}-y_{d}}\left(v_{T} t-x_{d}\right)+x d=f_{2}(y) \tag{3}
\end{align*}
$$

Equations representing the path of the driver's eye (i.e., the path of the origin of his line of sight) for each lane are:

$$
\begin{align*}
& L_{1}: y=y_{1}  \tag{4}\\
& L_{2}: y=y_{1}+W  \tag{5}\\
& L_{3}: y=y_{1}+2 W  \tag{6}\\
& L_{4}: y=y_{1}+3 W \tag{7}
\end{align*}
$$

in which

$$
\begin{aligned}
& W=\text { lane width; and } \\
& y_{1}=y \text { coordinate of the driver's eye in lane } 1 .
\end{aligned}
$$

In general, for $L_{n}$,

$$
\begin{equation*}
y=y_{1}+(n-1) W,(n=1,2, \ldots) \tag{8}
\end{equation*}
$$

If $y$ is replaced by $y_{1}+(n-1) W, A B$ and $D E$ become

$$
\begin{align*}
f_{1}(t, n)= & \frac{v_{T}\left[y_{1}+(n-1) W\right] t}{y_{12}}+\frac{\left[y_{1}+(n-1)\right]\left(x_{12}-x_{d}\right)}{y_{12}} \\
& +x_{d} \tag{9}
\end{align*}
$$

$$
\begin{align*}
f_{2}(t, n)= & \frac{v_{T}\left[y_{1}+(n-1) W-y_{d}\right] t}{\left(y_{11}-y_{d}\right)} \\
& +\left\{\frac{\left[y_{1}+(n-1) W-y_{d}\right]}{\left(y_{11}-y_{d}\right)}-1\right\} x_{d} \tag{10}
\end{align*}
$$

## Time Constants

A number of time constants that define limiting conditions for various cases must be derived. All these constants are measured from the time that corresponds to the initial position of the truck.

The first constant, $K_{n}$, in which $n$ is the lane number, represents the time at which the trailing edge of the boundary of the shadow changes from $x<0$ to $x=0$. It is clear that this parameter is essential in order to describe completely the behavior of the shadow as a function of time.

The time at which the truck's presence on the road ceases to have an effect on sign blockage is a second important time parameter. More precisely, this time, $t_{F}$, defines the instant when the truck no longer blocks the sign to any car within the portion of the road under discussion.

The constant, $T_{i}(n)$, represents the time such that a car starting before $T_{i}(n)$ could never be in the shadow. In other words, the car begins ahead of the shadow and
moves sufficiently rapidly to remain ahead for the rest of the time it is on the road. $T_{i}(n)$ is clcarly a function of the lane, $n$.

Another constant, $T_{s}(n)$, is the time at which the car begins ahead of the shadow. However, unlike $T_{i}(n)$, $t_{s} \geq T_{s}(n)$, in which $t_{s}$ is the starting time of the car, does not guarantee that the car will never be in the shadow. It is possible and likely that the car will move into the shadow at some later time. This is because the leading edge of the shadow moves faster than the car.

The times $T_{1}(n)$ and $T_{2}(n)$ are the limits of the car's time in the shadow. These limits are necessary to calculate the amount of time that any car spends within the shadow.

It should be noted that, under reasonable vehicle speed assumptions, if a car starts at time $t_{s}$ such that $K_{n}<t_{s} \leq t_{F}$, it can never be in the shadow. Thus, in addition to defining the time at which the boundary changes, $K_{n}$ also defines the time when a car, having started behind the shadow, cannot catch it, and thus must remain outside of it. In general,

$$
\begin{equation*}
K_{n}=\frac{(n-1) W x_{d}+x_{d}\left(y_{1}-y_{11}\right)}{v_{T}\left[y_{1}-y_{d}+(n-1) W\right]} \tag{11'}
\end{equation*}
$$

For the four lanes,
Lane $1(n=1) \quad K_{1}=\frac{x_{d}\left(y_{1}-y_{11}\right)}{v_{T}\left(y_{1}-y_{d}\right)}$
Lane $2(n=2) \quad \bar{K}_{2}=\frac{W x_{l}+x_{l l}\left(y_{1}-y_{11}\right)}{v_{T}\left(y_{1}-y_{\mathrm{d}}+W\right)}$
Lane $3(n=3) \quad K_{3}=\frac{2 W x_{d}+x_{d}\left(y_{1}-y_{11}\right)}{v_{T}\left(y_{1}-y_{d}+2 W\right)}$
Lane $4(n=4$
$K_{4}=\frac{3 W x_{d}+x_{d}\left(y_{1}-y_{11}\right)}{v_{T}\left(y_{1}-y_{d}+3 W\right)}$

In summary, if $I_{n}(t)$ is the interval whose endpoints define the shadow boundary for each lane $n$, then for any $n(n=1,2,3,4), f_{2}>0$ for all $t$ such that $K_{n}<t \leq t_{F}$ and

$$
\begin{equation*}
I_{n}(t)=\left[f_{2}(t), f_{1}(t)\right] \tag{16}
\end{equation*}
$$

If $0 \leq t \leq K$, because $f_{2} \leq 0$, then

$$
\begin{equation*}
I_{n}(t)=\left[0, f_{1}(t)\right] \tag{17}
\end{equation*}
$$

## Derivation of $K_{n}$

One wishes to find the time at which the boundary of the shadow changes from $\left(0, f_{1}\right)$ to $\left(f_{2}, f_{1}\right)$. The ( $0, f_{1}$ ) case holds whenever $f_{2} \leq 0$. Then,

$$
\begin{array}{r}
v_{T} t\left[y_{1}+(n-1) W-y_{d}\right]+\left[y_{1}+(n-1) W-y_{d}\right]- \\
x_{d}+x_{d}\left(y_{11}-y_{d}\right) \leq 0 \tag{18}
\end{array}
$$

$$
\begin{array}{r}
v_{T} t\left[y_{1}+(n-1) W-y_{d}\right] \leq x_{d}\left[\begin{array}{l}
y_{1}-y_{d}+(n-1) \\
x_{d}\left(y_{d}-y_{11}\right)
\end{array}\right. \\
\leq x_{d} y_{1}+x_{d}(n-1) W-x_{d} y_{11} \\
t \leq \tag{21}
\end{array}
$$

That is, $f_{2} \leq 0$ implies $t \leq K_{n}$ or $t>K_{n}$ implies $f_{2}>0$. Similarly, it can be shown that $f_{2}>0$ implies $t>K_{n}$. Thus, $f_{2} \leq 0$ if and only if $t \leq K_{n}$ or $f_{2}(t, n)$ is positive if and only if $t$ is greater than $K_{n}$.

## Derivation of $t_{F}$

It is necessary to find the time, $t_{F}$, at which the shadow will no longer appear on the portion of the road in question (i.e., between $x=0$ and $x=x_{F}$ ).

This is found by determining for the final truck position, $x=x_{F}$, the time at which $f_{2}$ intersects $y=y_{1}+\left(n_{L}-1\right)$ $W$, in which $n_{L}$ is the last lane.


For $n_{L}=4$, this becomes

$$
\begin{align*}
f_{2}(t, n)= & \frac{v_{T}\left(y_{1}+3 W-y_{d}\right) t}{\left(y_{11}-y_{d}\right)} \\
& {\left[\frac{\left(y_{1}+3 W-y_{d}\right)}{\left(y_{11}-y_{d}\right)}-1\right] x_{d}=x_{F} } \tag{22}
\end{align*}
$$

Solving for $t$

$$
\begin{equation*}
t=\frac{\left(x_{F}-x_{d}\right)\left(y_{11}-y_{d}\right)}{v_{T}\left(y_{1}+3 W-y_{d}\right)}+\frac{x_{d}}{v_{T}}=t_{F} \tag{23}
\end{equation*}
$$

Derivation of $T_{i}(n)$ - $\left[T_{\text {initial }}(n)\right]$
There exists a time, $T_{i}(n)$, for each lane, such that if $0<t_{s}<T_{i}(n)$, the car will never be in the shadow. That is, the car starts ahead of the shadow and maintains that situation (although it may get closer and closer to the shadow). If the car starts at $t_{s} \geq T_{i}(n)$, it will definitely be in the shadow at some time during its trip on the portion of road in question.

This time is found by equating the position of the car as a function of time, $t$; that is, $x_{n}(t)=\left(t-t_{s}\right) v_{c(n)}$ (where $v_{o(n)}$ is the car velocity in the $n$th lane) with $f_{1}(t, n)$ the leading edge of the shadow at time $t_{F}$. Thus:

$$
\begin{align*}
x_{n}(t)=\left(t_{F}-t_{s}\right) v_{c(n)}= & \frac{v_{T}\left[y_{1}+(n-1) W\right] t_{F}}{y_{12}} \\
& +\frac{\left[y_{1}+(n-1) W\right]\left(x_{12}-x_{d}\right)}{y_{12}} \\
& +x_{d} \tag{24}
\end{align*}
$$

$t_{8}=\frac{t_{F} v_{c(n)} y_{12}-v_{T}\left[y_{1}+(n-1) W\right] t_{F}}{-\left[y_{1}+(n-1) W\right]\left(x_{12}+x_{d}\right)-x_{d} y_{12}}$
This time is $T_{i}(n)$.
If $T_{i}(n)<0$, there is no possible starting time when the car can begin ahead of the shadow and stay ahead of it.

## Derivation of $T_{s}(n)-T_{s t a r t}(n)$

One now finds the time, $T_{s}(n)$, such that if a car starts at $t_{s}$, where $t_{s} \leq T_{s}(n)$, it will begin ahead of the shadow. If $T_{s}(n) \leq t_{s} \leq K_{n}$, the car begins inside the shadow.

To determine $T_{s}(n)$, consider the inequality

$$
\begin{align*}
x_{n}\left(t_{s}\right)=0 \leq & f_{1}\left(t_{s}, n\right)=\frac{v_{T}\left[y_{1}+(n-1) W\right]}{y_{12}} \\
& +\frac{\left[y_{1}+(n-1) W\right]\left(x_{12}-x_{d}\right)}{y_{12}}+x_{d} \tag{26}
\end{align*}
$$

Solving for $t_{s}$,

$$
\begin{gather*}
\frac{v_{T}\left[y_{1}+(n-1) W\right] t_{s}}{y_{12}} \geq \frac{\left(x_{d}-x_{12}\right)\left[y_{1}+(n-1) W\right]}{y_{12}}-x_{d}  \tag{27}\\
t_{s} \geq\left[\frac{\left(x_{d}-x_{12}\right)}{v_{T}}-\frac{\left(x_{d} y_{12}\right)}{v_{T}\left[y_{1}+(n-1) W\right]}\right]=T_{s}(n) \tag{28}
\end{gather*}
$$

Thus, as long as $t_{s} \geq T_{s}(n)$, the car begins in the shadow.
If $T_{s}(n)<0$, it means that no matter when the car starts at $t_{s} \leq K_{n}$, it starts inside the shadow. That is, there is no point where it can start ahead of the shadow.

## Derivation of $T_{1}(n)$ and $T_{2}(n)$ and Probabilities

For $x_{n}(t)$ to be in $I_{n}(t)$, there are four cases: the car starts at time $t_{s}$ such that

1. $0 \leq t_{s}<T_{i}(n)$
2. $T_{i}(n) \leq t_{s}<T_{s}(n)$
3. $T_{s}(n) \leq t_{s}<K_{n}$
4. $K_{n} \leq t_{s} \leq t_{F}$

In any case, for the car to be in the shadow it must be true that

$$
\begin{equation*}
f_{2}(t, n) \leq x_{n}(t) \leq f_{1}(t, n) \tag{33}
\end{equation*}
$$

in which $x_{n}(t)=\left(t-t_{f} \backslash v_{c(n)}\right.$.
These two inequalities, (1) $x_{n} \leq f_{1}(t, n)$ and (2) $x_{n} \geq$ $f_{2}(t, n)$, can be solved for $t$.
Solving (1) for $t$,

$$
t \geq \frac{\begin{array}{c}
{\left[y_{1}+(n-1) W-y_{12}\right] x_{d}} \\
-\left[y_{1}+(n-1) W\right] x_{12}-v_{c(n)} t_{s} y_{12} \tag{34a}
\end{array}}{v_{T}\left[y_{1}+(n-1) W\right]-y_{12} v_{c(n)}}
$$

or

$$
\begin{equation*}
t \geq T_{2}(n) \tag{34b}
\end{equation*}
$$

Solving (2) for $t$,
$t \leq \frac{x_{d}\left[y_{1}+(n=1) W-y_{11}\right]-\left(y_{11}-y_{d}\right) v_{c(n)} t_{s}}{v_{T}\left[y_{1}+(n-1) W-y_{d}\right]-\left(y_{11}-y_{d}\right) v_{c(n)}}=T_{1}(n)$
or

$$
\begin{equation*}
t \leq T_{1}(n) \tag{35b}
\end{equation*}
$$

If the car starts at $t_{s}<T_{i}(n)$, it will never be in the shadow. As long as the car starts at $t_{s} \geq T_{i}(n)$, with $T_{i}(n) \leq t_{i}$, it will be in the shadow for a total time $T_{1}(n)-T_{2}(n)$-that is, whenever $T_{i}(n) \leq t_{s}<T_{\mathrm{s}}(n)$.

When $T_{s} \leq t_{s}<K_{n}$, the car will be in the shadow for $T_{1}(n)-t_{s}$ seconds.

Because the maximum time that a car can be in the shadow is $t_{F}-t_{s}$, the corresponding probabilities are:
(1) $P_{n}{ }^{*}\left(t_{s}\right)=\frac{T_{1}(n)-T_{2}(n)}{t_{F}-t_{s}}$ when $T_{i}(n) \leq t_{s}<T_{s}$
(2) $P_{n}^{*}\left(t_{s}\right)=\frac{T_{1}(n)-t_{s}}{t_{F}-t_{s}}$ when $T_{s} \leq t_{s}<K_{n}$
or if $G\left(t_{s}\right)$ is defined as follows:

$$
G\left(t_{s}\right)=\left\{\begin{array}{l}
T_{2}(n), \text { when } 0 \leq t_{s}<T_{s}  \tag{38}\\
t_{s}, \text { when } T_{s} \leq t_{s}<K_{n}
\end{array}\right.
$$

then

$$
\begin{equation*}
P_{n}\left(t_{s}\right)=\frac{T_{1}(n)-G\left(t_{s}\right)}{t_{F}-t_{s}} \text { for } T_{i}(n) \leq t_{s}<K_{n} \tag{39}
\end{equation*}
$$

If $0 \leq t_{s}<T_{i}(n), P_{n}{ }^{*}\left(t_{s}\right)=0$ (because the shadow never reaches the car).
If $K_{n}<t_{s} \leq t_{F}, P_{n}^{*}\left(t_{s}\right)=0$ (because the shadow moves faster than the car).

If $T_{1}(n)>t_{F}$, the corresponding probabilities are:

$$
P=\frac{t_{F}-T_{2}(n)}{t_{F}-t_{s}} \quad P=\frac{t_{F}-t_{s}}{t_{F}-t_{s}}=1.0
$$

because $T_{1}(n)$ is replaced by $t_{F}$.

## Probability of Blockage

It is now possible to compute the probability that a random car is in the shadow for a time greater than ( $p \times 100$ ) percent of the total time that it is on the road.

One way to arrive at this (a simpler way is discussed later) is to choose a partition of $\left[0, t_{F}\right]$, where $t_{s} \in\left[0, t_{F}\right]$. Choose a set of points $t_{i} \in\left[0, t_{F}\right] ; i=1,2, \ldots$, such that $\left(t_{i+1}-t_{i}\right)=t_{F} /(N-1)$ and $t_{1}=0, t_{N}=t_{F}$. These points partition $\left[0, t_{F}\right]$ into $N-1$ equal intervals. Define a function $Q_{i, n}$ such that if $t_{s(i)}$ is any point in the interval ( $t_{i}, t_{i+1}$ ) and if $P_{n}\left(t_{s(i)}\right) \geq p$, then $Q_{i, n}=1$; if $P_{n}$ $\left(t_{s(i)}\right)<p$, than $Q_{i, n}=0$.

All the $Q_{i, n}$ 's are zero until some time $t_{1}$; then, they are all 1 until some time $t_{2}$, after which they again become all zeros.
There will be $(N-1)$ different starting intervals for a car for each lane and the $Q_{i, n}$ 's are summed. The sum $\sum_{i=0}^{N} Q_{i, n}$ divided by $N-1$ defines the probability that a
random car will have its vision blocked for at least ( $p \times 100$ ) percent of the time in lane $n$. For all four lanes, the probability becomes

$$
\begin{equation*}
P_{p}(t)=\frac{\sum_{n=1}^{4} \sum_{i=0}^{N} Q_{i, n}}{4(N-1)} \tag{40}
\end{equation*}
$$

A simpler way to arrive at this answer (actually the limit of this answer, as the mesh fineness of the partition becomes zero) depends on the continuous nature of the $Q_{i, n}$ 's.

It involves solving the equations of $P_{n}\left(t_{s}\right)$ for $t_{s}$, setting $P_{n}\left(t_{s}\right)=p$.

In general, there will be two points at which $P_{n}\left(t_{s}\right)=p$ and the curves will appear as:


There are two solutions: $t_{s(1)}$, the solution for $t_{s}<T_{s}$, and $t_{s(2)}$, the solution for $t_{s} \geq T_{s}$. For the first,

$$
\begin{equation*}
P_{n}\left(t_{s}\right)=\frac{T_{1}(n)-T_{2}(n)}{t_{F}-t_{s}} \tag{41}
\end{equation*}
$$

in which $T_{1}(n)$ is also a function of $t_{s}$. Because $T_{1}(n)$ has the form $A_{1}-B_{1} t_{s}$ and $T_{2}(n)$ has the form $A_{2}-B_{2} t_{s}$,

$$
\begin{gather*}
p=P_{n}\left(t_{s}\right)=\frac{A_{1}-B_{1} t_{s}-A_{2}+B_{2} t_{s}}{t_{F}=t_{s}}  \tag{42}\\
p t_{F}-p t_{s}=\left(A_{1}-A_{2}\right)-\left(B_{1}-B_{2}\right) t_{s}  \tag{43}\\
\left(B_{1}-B_{2}-p\right) t_{s}=\left(A_{1}-A_{2}\right)-p t_{F} \tag{44}
\end{gather*}
$$

and

$$
\begin{equation*}
t_{s}=\frac{\left(A_{1}-A_{2}\right)-p t_{F}}{\left(B_{1}-B_{2}-p\right)}=t_{s(1)} \tag{45}
\end{equation*}
$$

For the case $t_{s} \geq T_{s}$,

$$
\begin{gather*}
p=P_{n}\left(t_{s}\right)=\frac{T_{1}(n)-t_{s}}{t_{F}-t_{s}}=\frac{A_{1}-B_{1} t_{s}-t_{s}}{t_{F}-t_{s}} \\
=\frac{A_{1}-\left(B_{1}+1\right) t_{s}}{t_{F}-t_{s}}  \tag{46}\\
p t_{F}-A_{1}=\left[p-\left(B_{1}+1\right)\right] t_{s}  \tag{47}\\
t_{s}=\frac{p t_{F}-A_{1}}{p-\left(B_{1}+1\right)}=t_{s(2)} \tag{48}
\end{gather*}
$$

Then, the total time that $P_{n}\left(t_{s}\right) \geq p$ is $\left(t_{s(2)}-t_{s(1)}\right)$, and

$$
\begin{equation*}
P_{p}(t)=\frac{\left(t_{s(2)}-t_{s(1)}\right)}{t_{F}} \tag{49}
\end{equation*}
$$

## Numerical Calculations

Using the parameter values listed in the following, values of the time constants and blockage probabilities have
been computed. Figures 51 and 52 show the truck's shadow on a time-distance coordinate system for lanes

$$
k_{1}=\frac{3,000(5.4)}{88(19.4)}=9.50 \mathrm{sec}
$$ 1 and 2 , respectively.

|  | - |  |  |
| :--- | :---: | :--- | :---: |
| PARAMETER | VALUE | PARAMFTFR | VAT.IF |
| $x_{11}$ | 0 | $y_{1}+3 W$ | 71.4 |
| $x_{12}$ | 40 | $v_{T}$ | 88 |
| $x_{d}$ | 3,000 | $y_{12}$ | 38 |
| $x_{F}$ | 2,660 | $v_{o 1}$ | 88 |
| $y_{11}$ | 30 | $v_{c 2}$ | 95 |
| $y_{1}$ | 35.4 | $v_{o 3}$ | 103 |
| $y_{1}+W$ | 47.4 | $v_{o 4}$ | 103 |
| $y_{1}+2 W$ | 59.4 | $W$ | 12 |

$$
k_{2}=\frac{12(3,000)+3,000(5.4)}{88(31.4)}=18.90 \mathrm{sec}
$$

$$
k_{3}=\frac{24(3,000)+3,000(5.4)}{88(43.4)}=23.10 \mathrm{sec}
$$

$$
\begin{equation*}
k_{4}=\frac{36(3,000)+3,000(5.4)}{88(55.4)}=25.50 \mathrm{sec} \tag{50}
\end{equation*}
$$

$$
t_{F}=\frac{\left(x_{F}-x_{d}\right)\left(y_{11}-y_{d}\right)}{v_{T}\left(y_{1}+3 W-y_{d}\right)}-\frac{\left(x_{11}-x_{d}\right)}{v_{T}}
$$

Time Constants:

$$
\begin{array}{cc}
K_{n}=\frac{(n-1) W x_{d}+x_{d}\left(y_{1}-y_{11}\right)}{v_{T}\left[y_{1}+(n-1) W-y_{d}\right]} & =33.12 \mathrm{sec}  \tag{51}\\
T_{i}(n)=\frac{t_{F} v_{c(n)} y_{12}-v_{T}\left[y_{1}+(n-1) W\right] t_{F}-\left[y_{1}+(n-1) W\right]\left(x_{12}-x_{d}\right)-x_{d} y_{12}}{\left(y_{12}\right)\left(v_{c(n)}\right)}
\end{array}
$$

$$
=\frac{(2,660-3,000)(30-16)}{88(71.4-16)}+\frac{3,000}{88}
$$



Figure 51. Shadow for Lane 1.

$$
\begin{align*}
& T_{i}(1)<0 \\
& T_{i}(2)=2.34 \mathrm{sec} \\
& T_{i}(3)=4.71 \mathrm{sec} \\
& T_{i}(4)=3.95 \mathrm{sec} \\
& T_{s}(n)=\frac{x_{d}-x_{12}}{v_{T}}-\frac{x_{d} y_{12}}{v_{T}\left[y_{1}+(n-1) W\right.}  \tag{53}\\
& T_{8}(1)=\frac{(3,000-40)}{88}-\frac{(3,000)(38)}{(88)(35.4)}=2.65 \mathrm{sec} \\
& T_{s}(2)=\frac{(3,000-40)}{88}-\frac{(3,000)(38)}{(88)(47.4)}=6.25 \mathrm{sec} \\
& T_{s}(3)=\frac{(3,000-40)}{88}-\frac{(3,000)(38)}{(88)(59.4)}=11.85 \mathrm{sec} \\
& T_{s}(4)=\frac{(3,000-40)}{88}-\frac{(3,000)(38)}{(88)(71.4)}=15.45 \mathrm{sec} \\
& T_{1}(n)=\frac{x_{d}\left[y_{1}+(n-1) W-y_{11}\right]-\left(y_{11}-y_{d}\right) v_{c(n)} \cdot t_{s}}{v_{T}\left[y_{1}+(n-1) W-y_{d}\right]-\left(y_{11}-y_{d}\right) v_{c(n)}} \\
& T_{2}(n)=\frac{x_{d}\left[y_{1}+(n-1) W-y_{12}\right]-\left[y_{1}+(n-1) W\right] x_{12}-v_{c(n)} t_{s} y_{12}}{v_{T}\left[y_{1}+(n-1) W\right]-y_{12} v_{c(n)}}  \tag{55}\\
& T_{1}(1)=34.3-2.61 t_{s} \\
& T_{2}(1)=40.8+14.8 t_{s} \\
& T_{1}(2)=36.5-0.93 t_{s} \\
& T_{2}(2)=52.75-7.4 t_{s} \\
& T_{1}(3)=37.2-0.61 t_{s} \\
& T_{2}(3)=48.5-3.01 t_{s} \\
& T_{1}(4)=36.2-0.42 t_{s} \\
& T_{2}(4)=41.1-1.66 t_{s} \\
& P_{n}{ }^{*}\left(t_{s}\right)=0, \text { if } 0 \leq t_{s} \leq T_{i}(n) \\
& =\frac{T_{1}(n)-T_{2}(n)}{t_{F}-t_{s}}, \text { if } T_{i}(n) \leq t_{s}<T_{s}(n) \\
& =\frac{T_{1}(n)-t_{s}}{t_{F}-t_{s}} \text {, if } T_{s}(n) \leq t_{s} \leq K_{n} \\
& =0, \text { if } K_{n}<t_{s} \leq t_{F} \tag{54}
\end{align*}
$$



Figure 52. Shadow for Lane 2.

Lane 1:

$$
\begin{aligned}
P_{1} *\left(t_{s}\right) & =\frac{T_{1}(n)-t_{s}}{t_{F}-t_{s}}=\frac{34.3-3.61 t_{s}}{33.0-t_{s}},-2.65 \leq t_{s}<9.50 \\
P_{1}(0) & =1.0
\end{aligned}
$$

## Lane 2:

$$
\begin{aligned}
P_{2}\left(t_{s}\right) & =0, \quad 0 \leq t_{s}<2.34 \\
& =\frac{6.47 t_{s}-16.25}{33.0-t_{s}}, 2.34 \leq t_{s}<6.25 \\
& =\frac{3.65-1.93 t_{s}}{33.0-t_{s}}, 6.25 \leq t_{s}<18.90 \\
& =0, \quad 18.9 \leq t_{s}<33.0
\end{aligned}
$$

Lane 3:

$$
\begin{aligned}
P_{3}\left(t_{s}\right) & =0, \quad 0 \leq t_{s}<4.71 \\
& =\frac{2.40 t_{s}-11.3}{33.0-t_{s}}, 4.71 \leq t_{s}<11.85 \\
& =\frac{3.72-1.61 t_{s}}{33.0-t_{s}}, \\
& =0, \\
& 23.85 \leq t_{s}<23.10
\end{aligned}
$$

Lane 4:

$$
\begin{aligned}
P_{4}\left(t_{s}\right) & =0 \\
& =\frac{1.24 t_{s}-4.9}{33.0-t_{s}}, 3.95 \leq t_{s}<15.45
\end{aligned}
$$

$$
\begin{aligned}
& \begin{array}{l}
=\frac{36.2-1.42 t_{s}}{33.0-t_{s}}, 15.45 \leq t_{s}<25.50 \\
=0,
\end{array} \quad 25.50 \leq t_{s} \leq 33.0
\end{aligned}
$$

Table 20 and Figure 53 summarize the preceding calculations.

## Two Trucks-Horizontal Blockage

## Method of Extension

In the case of two trucks, a simplifying assumption is made to make the matter easier to handle while not detracting much from the generality. It is assumed that the trucks are equally spaced along the length of road in question. That is, the second truck appears when the first one has reached the center of the roadway.

Thus, in a manner completely analogous to the previous development, the same limiting conditions may be found for the case of two trucks meeting the restriction described previously. The equations for $f_{1}$ and $f_{2}$ are found for the second truck exactly as before. Denoted $f_{12}$ and $f_{21}$, they are, respectively,

$$
\begin{aligned}
& f_{12}(t)=f_{11}(t-T) \\
& f_{22}(t)=f_{21}(t-T)
\end{aligned}
$$

in which $T$ is the time delay in the start of the second truck.

Because the boundaries of both sets of shadows are now known and defined, the solutions can be found exactly


Figure 53. Plot of probability of blockage versus $\mathbf{p}$ for one truck.

TABLE 20
PROBABILITY OF BLOCKAGE VERSUS $p$ BY LANE FOR ONE TRUCK ${ }^{\text {a }}$

| $\boldsymbol{p}$ | LANE 1 | LANE 2 | LANE 3 | LANE 4 | TOTAL |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1.00 | 0.012 | 0.000 | 0.000 | 0.000 | 0.003 |
| 0.95 | 0.032 | 0.000 | 0.000 | 0.000 | 0.008 |
| 0.90 | 0.050 | 0.011 | 0.000 | 0.000 | 0.015 |
| 0.80 | 0.083 | 0.088 | 0.046 | 0.014 | 0.058 |
| 0.70 | 0.113 | 0.159 | 0.129 | 0.111 | 0.128 |
| 0.60 | 0.142 | 0.221 | 0.202 | 0.194 | 0.181 |
| 0.50 | 0.168 | 0.274 | 0.267 | 0.268 | 0.244 |
| 0.40 | 0.193 | 0.323 | 0.326 | 0.339 | 0.295 |
| 0.30 | 0.216 | 0.367 | 0.383 | 0.408 | 0.334 |
| 0.20 | 0.239 | 0.407 | 0.437 | 0.478 | 0.381 |
| 0.10 | 0.260 | 0.445 | 0.489 | 0.554 | 0.437 |
| 0.05 | 0.271 | 0.468 | 0.518 | 0.591 | 0.462 |
| 0.00 | 0.280 | 0.492 | 0.545 | 0.637 | 0.488 |

${ }^{\text {a }} p=$ car blocked at least $(p \times 100) \%$ of the time.
as before. This requires the computations of the new constants:
$K_{12}, K_{22}, K_{32}, K_{42} ; t_{F(2)} ; T_{i(2)}(1)$,

$$
T_{i(2)}(2), T_{i(2)}(3), T_{i(2)}(4)
$$

$T_{S(2)}(1), T_{S(2)}(2), T_{S(2)}(3)$,

$$
T_{S(2)}(4) ; T_{12}(1), T_{12}(2), T_{12}(3), T_{12}(4)
$$

$T_{22}(1), T_{22}(2), T_{22}(3), T_{22}(4)$; $T_{1}{ }^{\prime}(1), T_{1}{ }^{\prime}(2), T_{1}{ }^{\prime}(3), T_{1}{ }^{\prime}(4) ;$ $T_{2}{ }^{\prime}(1), T_{2}{ }^{\prime}(2), T_{2}{ }^{\prime}(3), T_{2}{ }^{\prime}(4)$.
The derivation of these constants is the same as indicated previously in "Single Truck-Horizontal Blockage"; however, their numerical values are different. $T_{1}{ }^{\prime}(n)$ and $T_{2}{ }^{\prime}(n)$ are analogous to $T_{1}(n)$ and $T_{2}(n)$. They refer to the second truck. In general,

$$
T_{12}(n)=T_{1}(n)+T_{1}^{\prime}(n)
$$

and

$$
T_{22}(n)=T_{2}(n)+T_{2}^{\prime}(n)
$$

Now all that need be done is find the amount of time that cars are in the later shadow. Because it is already known how much time cars spend in the original shadow (given their starting times), the total time spent in shadow can easily be found to be the sum of the two. Thus, the probabilities are computed, just as before, and the new curves are drawn.

The calculations and diagrams for the two-truck case corresponding to the material in "Single Truck-Horizontal Blockage" are shown in the following. Again, probabilities are computed and tabulated as before.

Lane 1 (2 trucks) (Fig. 54):

$$
\begin{aligned}
T_{s(2)} & =16.5+T_{s(1)}=13.5 \mathrm{sec} \\
K_{12} & =16.5+K_{11}=16.50+9.50=26.0 \mathrm{sec} \\
& =T_{12}(1)=T_{1}(1)+T_{1}{ }^{\prime}(1) \\
T_{12}(1) & =34.3-2.61 t_{s}+T_{1}^{\prime}(1)
\end{aligned}
$$

$$
\begin{aligned}
&= 34.3-26.1 t_{s}+\frac{88(19.4)(16.5)}{88(19.4)-14(88)} \\
&= \frac{288,220}{480}+34.3-2.61 t_{s} \\
& T_{12}(1)= 93.1-2.6 t_{s} \\
& T_{22}(1)= 40.8+14.8 t+T_{2}^{\prime}(1) \\
&= 40.8+14.8 t+\frac{35.4(88)(16.5)}{88(35.4)-88(38)} \\
&-182.0+14.7 t_{s} \\
& T_{22}(1)=-182.04+14.7 t_{s} \\
& K_{11} \leq t_{s} \leq T_{i(2)}(1), P=0 \\
& T_{i(2)}(1)=T_{i(1)}(1)+16.5=15.35 \mathrm{sec}
\end{aligned}
$$

for

For any $t_{s}$ such that $K_{11}=9.50 \leq t_{s} \leq T_{s(2)}=13.35$, $P=0$ and

$$
\begin{aligned}
P & =\frac{T_{2}-t_{s}}{t_{F}-t_{s}} \text { when } 13.35 \leq t_{s} \leq 15.35 \\
P & =\frac{t_{F}-t_{s}}{t_{F}-t_{s}}=1.0 \text { when } 15.35 \leq t_{s} \leq K_{12}=26.0 \\
P & =0 \quad \text { when } 26.0 \leq t_{s} \leq 33
\end{aligned}
$$

Lane 2 (2 trucks) (Fig. 55):

$$
\begin{aligned}
T_{s(2)} & =22.75 \mathrm{sec} \\
K_{22} & =35.9 \mathrm{sec} \\
& =36.5-0.93 \quad t_{s}+T_{1}{ }^{\prime}(2) \\
T_{22}(2)= & 36.5-0.93 \quad t_{s}+\frac{88(47.4-16) 16.5}{88(31.4)-14(95)} \\
& =36.5-0.93 \quad t_{s}+\frac{45,550}{1,430} \\
& =36.5-0.93 \quad t_{s}+31.8 \\
& =68.3-0.93 \quad t_{s} \\
T_{22}(2) & =52.75-7.4 \quad t_{s}+T_{2}{ }^{\prime}(1)=167-6.35 \quad t_{s} \\
T_{i(2)}(2) & =16.5+2.34=18.84 \\
T_{i} & =21.10 \mathrm{sec} \\
P & =0 \\
P & =\frac{t_{F}-T_{2}}{t_{F}-t_{s}} \quad 218.9 \leq t_{s}<21.10 \\
P & =1.0 \quad 22.75 \leq t_{s} \leq 33
\end{aligned}
$$

Lane 3 (2 trucks) (Fig. 56):

$$
\begin{aligned}
& T_{s(2)}=28.00 \\
& T_{29}(3)=48.5-3.01 t_{s}+T_{2}{ }^{\prime}(2) \\
& =113.0-3.03 t_{s} \\
& T_{i(2)}(3)=21.21 \\
& K_{31}=23.1 \\
& P=0 \\
& 23.1 \leq t_{s}<26.4 \\
& P=\frac{t_{F}-T_{2}}{t_{F}-t_{s}} \\
& P=1.0 \\
& K_{31}=26.4 \leq t_{s}<28.00 \\
& 28.00 \leq t_{s} \leq 33
\end{aligned}
$$



Figure 54. Shadow for Lane 1, two trucks.

$$
\begin{aligned}
137(33-165)-1,580 & =103\left(33-t_{s}\right)=3,400-103 t_{s} \\
2,260-1,580 & =3,400-103 t_{s} \\
680 & =3,400-103 t_{s} \\
103 t_{s} & =2,720 \\
t_{s} & =26.4 \mathrm{sec}
\end{aligned}
$$

Lane 4 (2 trucks) (Fig. 57):

$$
\begin{aligned}
& T_{s(2)}= 31.95 \\
& T_{22}(4)=41.1-1.66 t_{s}+T_{2}^{\prime}(4) \\
&=84.0-1.64 t_{s} \\
& v_{c}\left(t-t_{s}\right)=f_{1}(t-\mathrm{T}) \\
& 103\left(33-t_{s}\right)= 166(t-16.5)-2,540 \\
&-103 t_{s}= 3,200 \\
& t_{s}= 31.1 \mathrm{sec} \\
& P=0 \quad \text { when } 25.5 \leq t_{s}<31.1 \\
& P=\frac{t_{F}-T_{2}}{t_{F}-t_{s}} \quad 31.1 \leq t_{s}<31.45
\end{aligned}
$$

$P=1.0$
$31.95 \leq t_{s} \leq 33$
Table 21 summarizes these calculations for each of the four lanes. The curves of Figure 58 show that because the shadows never overlap, the curves remain the same as for one truck until time $T_{i(2)}(n)$. At that point, they will rise sharply to 1.0 . This means that any car starting out beyond $T_{i(2)}(n)$ has a high probability of being in the shadow a great deal of the time.

This effect results in shifting the curve of Figure 59 upward. That is, there is a higher probability that the sign is blocked at least ( $p \times 100$ ) percent of the time than there was for the case of a single truck.

An actual use of Figure 59 can be pointed out by the following example. For a four-lane highway with all parameters defined as in this discussion, and with one truck on the road portion under examination, the curve reveals that the probability of a random driver's vision being blocked by the truck at least 40 percent of the time is 30.5 percent. For the same case, but now with two trucks on the road, the probability increases to 59.0 percent.


Figure 55. Shadow for Lane 2, two trucks.

Within the limitations of this development, it can be shown that the results are of a very general nature. That is, there is a relation between the foregoing conclusions and the ADT. The relationship is subtle because it is not immediately apparent. If the ADT and the corresponding percentage of trucks in the volume are known, a unique curve can be obtained. Therefore, the effect of changing ADT and truck percentage can be seen by plotting more of these curves and studying the results. The cases gone into previously are those of one and two trucks per 3,000 ft of road.

According to the derivations, the car in question is random; it has an equal probability of being anywhere along the road. The result states that this car has a given probability of having its vision blocked (with relation to the sign) for various levels of blockage and various number of trucks (thus, various ADT's).

## EFFECTS OF LATERAL SIGN DISPLACEMENT

Recent efforts to increase the safety of highway travel have included attempts to make the highway more forgiving, especially by creating clear recovery areas adjoining the
traveled way. This has resulted in increasing the lateral distance between the edge of the roadway and the location of major guide signs. An analytical investigation of the effect that this lateral sign displacement has on the legibility of the sign is presented here.

The basic approach used in this analysis was first developed by Mitchell and Forbes (130). A driver is assumed to start reading a sign when it first becomes legible, and finish reading it before he reaches a point at which the sign falls outside the normal field of vision. The point of first legibility is a function of letter height: the field of vision is defined in terms of the maximum divergence angle.

## Signs on Tangent

In Figure $60, \theta$ is the acceptable maximum divergence angle and, therefore, $B$ is the point at which the driver should have finished reading the sign message. If $t$ is the time in seconds necessary to read the sign, the vehicle, traveling along the path $M N$, will traverse $t V$ feet during that time, where $V$ is the velocity in feet per second. The sign must therefore be legible at point $C$, a distance $t V$ feet upstream from $B$. For the case of a three-lane high-


Figure 56. Shadow for Lane 3, two trucks.
way with 12 -ft lanes, and the driver's eye position assumed to be $2 / 3$ of the lane width to the left, point $B$ is ( $S+$ $32+W / 2) \cot \theta$ feet upstream from point $A$, the location of the sign, in which $S$ is the lateral displacement of the edge of the sign, in feet, measured normal to the path of travel, and $W$ is the width of the sign, in feet. The distance at which the sign must become legible is therefore represented by $C D$, which can be expressed, for tangent approaches, as

$$
\begin{equation*}
C D=\sqrt{[t V+(S+32+W / 2) \cot \theta]^{2}+[S+32+W / 2]^{2}} \tag{56}
\end{equation*}
$$

If $L$ is the reading distance in feet per inch of letter height, the required minimum letter height, $H$ (in inches), becomes

$$
\begin{equation*}
H=\frac{\sqrt{[t V+(S+32+W / 2) \cot \theta]^{2}+[S+32+W / 2]^{2}}}{L} \tag{57}
\end{equation*}
$$

Eq. 57 includes five variables. $V$ and $S$ are determined for the specific highway and specific sign position being investigated. The other variables are determined by human factors considerations.

Mitchell and Forbes derived an expression for $t$ in terms of $N$, where $N$ is defined as the "number of familiar words on the sign." This expression is derived on the basis of $1-\mathrm{sec}$ glances from the road to the sign and back to the road, and the ability to read three familiar words during each glance. Adding a safety factor of 1 sec , this expression is:

$$
\begin{equation*}
t=(N / 3)+1.0 \tag{58a}
\end{equation*}
$$

Later work at the British Road Research Laboratory (RRL), reported by Moore and Christie (131), indicated that a more appropriate formula, designed to give the driver two chances to read the sign and cover the case where the name searched for is the last to be read, is:

$$
\begin{equation*}
t=(2 N / 3) \tag{58b}
\end{equation*}
$$

Continuing work at the RRL has resulted in the selection of the following formula for determining letter sizes in preparing the British sign standards (99):

$$
\begin{equation*}
t=0.31 N+1.94 \tag{58c}
\end{equation*}
$$

Eqs. 58a, 58b, and 58c are plotted in Figure 61.


Figure 57. Shadow for Lane 4, two trucks.

In Mitchell's and Forbes' original work, a value of $\theta=10^{\circ}$, based on psychological considerations, was assumed. This value is now generally accepted in Great Britain (99) as well as in the United States (9). In Germany, on the other hand, a value of $\theta=15^{\circ}$ is used (158). Heller (158) also gives a curve relating $t$ and $N$. However, because $N$ is defined as "syllables," the results cannot be compared with the equations given previously.
$L$ is defined as legibility in feet per inch of letter height, assuming a straight-line relationship. Mitchell and Forbes use a value of $50 \mathrm{ft} / \mathrm{in}$. British practice is the same for lower-case letters. For upper-case letters, a value of 37.5 $\mathrm{ft} / \mathrm{in}$. is advocated. Moore and Christie point out, however, that for the minimum legal vision requirements in the United Kingdom, $L$ should equal $21 \mathrm{ft} / \mathrm{in}$. Using the subtended angle definition of visual acuity (13), it can be computed that $20 / 20$ vision results in $L=57 \mathrm{ft} / \mathrm{in}$. For $20 / 70$ vision,* $L=16 \mathrm{ft} / \mathrm{in}$. It should be pointed out that these figures represent daylight or equivalent illumination. Allen et al. (133) have shown that legibility

[^19]distances decrease markedly when sign luminance drops below 20 foot-lamberts.
A special AASHO committee (159) has recommended that a clear recovery area of 30 ft from the edge of the traveled way be established. The maximum speed limit on any section of the Interstate system is 80 mph or 117 fps. Using $\theta=10^{\circ}, S=30$, and $t=0.31 N+1.94$, Eq. 57 can be written as
\[

$$
\begin{array}{r}
L H=\sqrt[2]{[(0.31 N+1.94) 117.0+(0.5 W+62)} \\
\cot 10]^{2}+(0.5 W+62)^{2} \tag{59}
\end{array}
$$
\]

The term $L H$ permits computation of letter height under various assumptions for $L$. The value of this term can be seen to be a function of message content, $N$, and sign size, $W$. The sign size, in turn, is a function of letter height and message content, because a change in either letter height or message length will lead to an increased sign panel size.

If the definition of $N$ is expanded to include numerals and familiar shapes and symbols such as shields and

TABLE 21
CALCULATION OF PROBABILITY OF BLOCKAGE VERSUS $p$ FOR TWO TRUCKS

|  | LANE 1 |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| p | $\mathrm{t}_{\mathrm{s}_{1}}$ | $\mathrm{t}_{\mathrm{s}_{2}}=\Delta_{1}$ | $\mathrm{t}_{\mathrm{s}_{3}}$ | $\mathrm{t}_{\mathrm{s}_{4}}$ | $\Delta_{2}$ | $\Delta_{1}+\Delta_{2}$ | $\mathrm{P}_{2}=\frac{\Delta_{1}+\Delta_{2}}{33}$ |
| 1.00 | 0 | 0.4 | 15.35 | 33 | 17.65 | 18.05 | 0.547 |
| 0.95 | 0 | 1.2 | 14.60 | 33 | 18.40 | 19.60 | 0.593 |
| 0.90 | 0 | 1.7 | 14.50 | 33 | 18.5 | 20.2 | 0.612 |
| 0.80 | 0 | 2.9 | 14.4 | 33 | 18.6 | 21.5 | 0.651 |
| 0.70 | 0 | 3.9 | 14.2 | 33 | 18.8 | 22.7 | 0.687 |
| 0.60 | 0 | 4.8 | 14.1 | 33 | 18.9 | 23.7 | 0.718 |
| 0.50 | 0 | 5.8 | 14.0 | 33 | 19.0 | 24.8 | 0.752 |
| 0.40 | 0 | 6.6 | 13.8 | 33 | 19.2 | 25.8 | 0.780 |
| 0.30 | 0 | 7.4 | 13.7 | 33 | 19.3 | 26.7 | 0.810 |
| 0.20 | 0 | 8.2 | 13.6 | 33 | 19.4 | 27.6 | 0.837 |
| 0.10 | 0 | 8.9 | 13.4 | 33 | 19.6 | 28.5 | 0.864 |
| 0.05 | 0 | 9.2 | 13.3 | 33 | 19.7 | 28.9 | 0.875 |

LANE 2

|  | $t_{s_{1}}$ | $t_{s_{2}}=\Delta_{1}$ | $t_{s_{3}}$ | $t_{s_{4}}$ | $\Delta_{2}$ | $\Delta_{1}+\Delta_{2}$ | $P_{2}=\frac{\Delta_{1}+\Delta_{2}}{33}$ |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.00 | 0 | 0 | 0 | 22.9 | 33 | 10.1 | 10.1 | 0.306 |
| 0.95 | 0 | 0 | 0 | 22.6 | 33 | 10.4 | 10.4 | 0.316 |
| 0.90 | 6.2 | 6.4 | 0.2 | 22.5 | 33 | 10.5 | 10.7 | 0.325 |
| 0.80 | 5.8 | 8.9 | 3.1 | 22.4 | 33 | 10.6 | 13.7 | 0.416 |
| 0.70 | 5.4 | 10.9 | 5.5 | 22.2 | 33 | 10.8 | 16.3 | 0.494 |
| 0.60 | 5.0 | 12.6 | 7.6 | 22.1 | 33 | 10.9 | 18.5 | 0.561 |
| 0.50 | 4.6 | 14.1 | 9.5 | 21.9 | 33 | 11.1 | 20.6 | 0.625 |
| 0.40 | 4.3 | 15.3 | 11.0 | 21.8 | 33 | 11.2 | 22.2 | 0.674 |
| 0.30 | 3.9 | 16.4 | 12.5 | 21.6 | 33 | 11.4 | 23.9 | 0.725 |
| 0.20 | 3.5 | 17.3 | 13.8 | 21.5 | 33 | 11.5 | 25.3 | 0.767 |
| 0.10 | 3.0 | 18.1 | 15.1 | 21.4 | 33 | 11.6 | 26.7 | 0.810 |
| 0.05 | 2.6 | 18.5 | 15.9 | 21.3 | 33 | 11.7 | 27.6 | 0.837 |

## LANE 3

|  | ${ }^{\mathrm{t}} \mathrm{s}_{1}$ | $\mathrm{t}_{s_{2}}$ | $\Delta_{1}$ | $\mathrm{t}_{\mathrm{s}_{3}}$ | $\mathrm{t}_{\mathrm{s}_{4}}$ | $\Delta_{2}$ | $\Delta_{1}+\Delta_{2}$ | $\mathrm{P}=\frac{\Delta_{1}+\Delta_{2}}{33}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.00 | 0 | 0 | 0 | 28.0 | 33 | 5.0 | 5.0 | 0.151 |
| 0.95 | 0 | 0 | 0 | 27.9 | 33 | 5.1 | 5.1 | 0.154 |
| 0.90 | 0 | 0 | 0 | 27.85 | 33 | 5.15 | 5.15 | 0.156 |
| 0.80 | 11.7 | 13.4 | 1.7 | 27.8 | 33 | 5.2 | 6.9 | 0.209 |
| 0.70 | 11.1 | 15.5 | 4.4 | 27.6 | 33 | 5.4 | 9.8 | 0.297 |
| 0.60 | 10.4 | 17.3 | 6.9 | 27.5 | 33 | 5.5 | 12.4 | 0.376 |
| 0.50 | 9.6 | 18.7 | 9.1 | 27.4 | 33 | 5.6 | 14.7 | 0.446 |
| 0.40 | 8.8 | 19.8 | 11.0 | 27.2 | 33 | 5.8 | 16.8 | 0.510 |
| 0.30 | 7.9 | 20.8 | 12.9 | 27.0 | 33 | 6.0 | 18.9 | 0.574 |
| 0.20 | 6.9 | 21.7 | 14.8 | 26.9 | 33 | 6.1 | 20.9 | 0.634 |
| 0.10 | 5.8 | 22.5 | 16.7 | 26.7 | 33 | 6.3 | 23.0 | 0.697 |
| 0.05 | 5.3 | 22.8 | 17.5 | 26.6 | 33 | 6.4 | 23.9 | 0.725 |

arrows its value can be determined for actual signs. For instance, the advance guide sign shown in the Interstate Manual (93, Fig. 7) has a value of $N=7$. Using the specified letter sizes and common spacing rules, this sign has a $W$ of about 20 ft . Eq. 59 becomes:

$$
\begin{aligned}
L H & =\sqrt[2]{[(2.17+1.94) 117.0+(10+62) 5.671]^{2}+} \\
& =892
\end{aligned}
$$

The required letter heights, for various assumptions as to the value of $L$ discussed previously, are given in Table 22.

The manual specifies $18-\mathrm{in}$. numerals and $12-\mathrm{in}$. capitals for this type of sign. This table indicates that, although the numerals are adequate for $L=50$, the letters are not and should be increased. It is obvious that an increase in letter height will result in a larger sign panel and will require recomputation of the table. Because there is no easy formula relationship between letter height and message length, the required letter height must be determined by successive approximations.

Table 23 gives the letter height required for various combinations of $W$ and $N$ under the assumptions previously stated and for $L=50$. Using the Mitchell and Forbes equation instead of the RRL formula would reduce each value in Table 23 by about 2 in.

Figure 60 shows that $\theta$ was measured to the center of the sign. For small values of $W$, this method has no appreciable effect. For larger values of $W$, however, the right-hand side of the sign may be considerably outside the field of vision. To include the entire sign in the field of vision, the term $(0.5 W+62)$ in Eq. 59 must be replaced by $(W+62)$. This will increase each letter height in Table 22 by about $0.057 W$ in.


Figure 58. Probability (position of total time) that sign is blocked versus starting time (as a function of lane, $\mathrm{L}_{\mathrm{n}}$ ).

Figure 59. Plot of probability blockage versus p for one truck and two trucks.


TABLE 22
LETTER HEIGHTS

| $L$ (FT/IN.) | $H$ (IN.) | NOTES |
| :--- | :--- | :--- |
| 57 | 15.7 | 20/20 vision |
| 50 | 17.8 | "Rule of thumb" |
| 37.5 | 23.8 | U.K. standard for lower-case letters |
| 28 | 31.9 | 20/40 vision |
| 21 | 42.5 | U.K. minimum visual acuity |
| 16 | 55.8 | 20/70 vision |

TABLE 23
LETTER HEIGHT REQUIRED FOR VARIOUS $W$ AND $N$

| $W$ | Letter height required (in.), by $N$ |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 10 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 20 | 21 | 22 | 23 | 23 |
| 15 | 15 | 16 | 16 | 17 | 18 | 19 | 19 | 20 | 21 | 21 | 22 | 23 | 23 |
| 20 | 15 | 16 | 17 | 18 | 18 | 19 | 20 | 20 | 21 | 22 | 22 | 23 | 24 |
| 25 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 21 | 21 | 22 | 23 | 23 | 24 |
| 30 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 22 | 22 | 23 | 24 | 24 |
| 35 | 16 | 17 | 18 | 18 | 19 | 20 | 20 | 21 | 22 | 23 | 23 | 24 | 25 |
| 40 | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 21 | 22 | 23 | 24 | 24 | 25 |
| 45 | 17 | 17 | 18 | 19 | 20 | 20 | 21 | 22 | 22 | 23 | 24 | 24 | 25 |
| 50 | 17 | 18 | 19 | 19 | 20 | 21 | 21 | 22 | 23 | 23 | 24 | 25 | 26 |
| 55 | 17 | 18 | 19 | 19 | 20 | 21 | 22 | 22 | 23 | 24 | 24 | 25 | 26 |
| 60 | 18 | 18 | 19 | 20 | 21 | 21 | 22 | 23 | 23 | 24 | 25 | 25 | 26 |

$$
L=50 \mathrm{ft} / \mathrm{in} . ; V=80 \mathrm{mph} ; t=0.31 N+1.94 ; \theta=10 ; \text { and } S=30 \mathrm{ft}
$$

TABLE 24
MAXIMUM OFFSET ( $S+0.5 W$ ) FOR VARIOUS DEGREES OF CURVATURE

| DEGREE OF <br> CURVATURE | MAXIMUM <br> OFFSET | DEGREE OF <br> CURVATURE $^{\text {a }}$ | MAXIMUM <br> OFFSET |
| :--- | :--- | :--- | :--- |
| 0.1 | 870 | 2.0 | 43 |
| 0.2 | 435 | 2.1 | 41 |
| 0.3 | 290 | 2.2 | 39 |
| 0.4 | 217 | 2.3 | 37 |
| 0.5 | 174 | 2.4 | 36 |
| 0.6 | 145 | 2.5 | 34 |
| 0.7 | 124 | 2.6 | 33 |
| 0.8 | 108 | 2.7 | 32 |
| 0.9 | 96 | 3.0 | 29 |
| 1.0 | 87 | 3.5 | 24 |
| 1.1 | 79 | 4.0 | 21 |
| 1.2 | 72 | 4.5 | 19 |
| 1.3 | 66 | 5.0 | 17 |
| 1.4 | 62 | 6.0 | 14 |
| 1.5 | 58 | 7.0 | 12 |
| 1.6 | 54 | 8.0 | 10 |
| 1.7 | 51 | 9.0 | 9 |
| 1.8 | 48 | 10.0 | 8 |
| 1.9 | 45 |  |  |

[^20]
## Signs on Curves

The discussion so far has been limited to tangent highway sections. The same approach can be used for curves. Figures 62 and 63 show, respectively, the geometry of sign location for curves to the right and to the left. Using simple geometric and trigonometric relationships, it can be shown that the corresponding equations are:

For curves to the right:

$$
L H=\sqrt[2]{a=(57.296 t V) / R+90-\delta+\theta} ⿻ \begin{array}{r}
2 R(R-S-0.5 W) \cos a \\
R^{2}+(R-S-0.5 W)^{2}- \\
20 b)
\end{array}
$$

For curves to the left:

$$
L H=\sqrt[2]{\frac{2}{R^{2}+(R+S+0.5 W)^{2}-}} \frac{(57.296 t V) / R+90-\delta+\theta}{2 R(R+S+0.5 W) \cos a}
$$

Before some of the results computed from this relationship are discussed it should be pointed out that, in the case of curve sections, two limiting cases must be considered that did not apply in the case of tangent sections. The first of these limitations occurs because the geometry of the sign location may be such that no point on the curve exists from which the deflection angle measured to the sign is $\theta^{\circ}$ or less. This will occur when $S+0.5 W$ is greater than $R(1-\cos \theta)$. Even when this condition does not occur it is possible for the divergence angle to exceed its maximum allowable value of $\theta$ at some point in the reading distance, $t V$.

Table 24 gives, for various degrees of curvature, the maximum offset $(S+0.5 W)$ that will result in at least one point on the curve having a deflection angle of $10^{\circ}$ or less. It can be seen that, for a vehicle traveling in the left-hand lane of two- or three-lane highways and with an offset of 30 ft , all curves to the right with a degree of curvature of $1.5^{\circ}$ or more will result in signs being completely out of the normal field of vision.

Table 25 gives the effect of changing the permissible value of $\theta$. For each value of $\theta$ and for each degree of curvature the maximum offset is given. It can be seen that, roughly, for each increase of $1^{\circ}$ in the maximum permissible value of $\theta$ the maximum degree of curvature is increased by $1 / 2^{\circ}$.

Tables 24 and 25 have been computed for positive values (curves to the right) only; the limitation of no point on the curve showing a divergence angle of $\theta$ or less does not apply to curves to the left. However, the second limitation, some point within the reading distance having a divergence angle of more than $\theta$, can apply.

The length of the reading distance $(t V)$ is a function of reading time and velocity. Using standard sign 7 of the Interstate Manual (93) again, $N=7, W=20 \mathrm{ft}$. Table 26 indicates the effect on letter size of varying the velocity. The effect of the two limiting factors can be seen.


Figure 62. Geometry of sign location-horizontal displacement-curve to right.


Figure 63. Geometry of sign location-horizontal displacement-curve to left.

TABLE 25
MAXIMUM OFFSET $(S+0.5 W)$ AS A FUNCTION OF $\theta$ AND DEGREE OF CURVATURE

| $\theta$ | MAXIMUM OFFSET, BY DEGREE OF CURVATURE |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 |
| 5.0 | 43 | 21 | 14 | 10 | 8 | 7 | 6 | 5 | 4 | 4 |
| 6.0 | 62 | 31 | 20 | 15 | 12 | 10 | 8 | 7 | 6 | 6 |
| 7.0 | 85 | 42 | 28 | 21 | 17 | 14 | 12 | 10 | 9 | 8 |
| 8.0 | 111 | 55 | 37 | 27 | 22 | 18 | 15 | 13 | 12 | 11 |
| 9.0 | 141 | 70 | 47 | 35 | 28 | 23 | 20 | 17 | 15 | 14 |
| 10.0 | 174 | 87 | 58 | 43 | 34 | 29 | 24 | 21 | 19 | 17 |
| 11.0 | 210 | 105 | 70 | 52 | 42 | 35 | 30 | 26 | 23 | 21 |
| 12.0 | 250 | 125. | 83 | 62 | 50 | 41 | 35 | 31 | 27 | 25 |
| 13.0 | 293 | 146 | 97 | 73 | 58 | 48 | 41 | 36 | 32 | 29 |
| 14.0 | 340 | 170 | 113 | 85 | 68 | 56 | 48 | 42 | 37 | 34 |
| 15.0 | 390 | 195 | 130 | 97 | 78 | 65 | 55 | 48 | 43 | 39 |
| 16.0 | 443 | 221 | 147 | 110 | 88 | 73 | 63 | 55 | 49 | 44 |
| 17.0 | 500 | 250 | 166 | 125 | 100 | 83 | 71 | 62 | 55 | 50 |
| 18.0 | 560 | 280 | 186 | 140 | 112 | 93 | 80 | 70 | 62 | 56 |
| 19.0 | 624 | 312 | 208 | 156 | 124 | 104 | 89 | 78 | 69 | 62 |
| 20.0 | 691 | 345 | 230 | 172 | 138 | 115 | 98 | 86 | 76 | 69 |

TABLE 26
EFFECT OF APPROACH SPEED ON REQUIRED LETTER SIZE ${ }^{\wedge}$

| D | letter gize (ind), dy aptroncil gredd (mpin) |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 |
| -5.0 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 13 | 0 | 0 | 0 | 0 | 0 |
| -4.5 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 0 | 0 | 0 | 0 |
| -4.0 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 0 | 0 | 0 |
| -3.5 | 7 | 8 | 9 | 9 | 10 | 11 | 12 | 13 | 14 | 16 | 17 | 0 | 0 |
| -3.0 | 8 | 8 | 9 | 10 | 10 | 11 | 12 | 13 | 15 | 16 | 17 | 18 | 0 |
| -2.5 | 8 | 8 | 9 | 10 | 11 | 12 | 12 | 14 | 15 | 16 | 17 | 19 | 20 |
| -2.0 | 8 | 9 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 18 | 19 | 21 |
| -1.5 | 8 | 9 | 10 | 10 | 11 | 12 | 13 | 14 | 15 | 17 | 18 | 19 | 21 |
| -1.0 | 9 | 9 | 10 | 11 | 12 | 12 | 13 | 15 | 16 | 17 | 18 | 20 | 21 |
| -0.5 | 9 | 10 | 11 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 19 | 20 | 22 |
| 0. | 10 | 11 | 11 | 12 | 13. | 14 | 15 | 16 | 17 | 18 | 19 | 21 | 22 |
| 0.5 | 11 | 12 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 21 | 22 | 23 |
| 1.0 | 13 | 14 | 15 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 23 | 24 | 26 |
| 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2.0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3.0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4.0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5.0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | , | 1 | 1 |

${ }^{n}$ A value of 0 denotes that the divergence angle exceeds $10^{\circ}$ at point of beginning legibility. A value of 1 denotes that the divergence angle exceeds $10^{\circ}$ for all points on the curve.

A computer program has been written embodying the relationship of Eqs. 56, 60, and 61. This program permits quick determination of required letter height for any combination of approach speed, sign size, message and offset. Table 27 gives a typical computer run relating sign size and message content for various degrees of curvature and for the following parameters: $V=70 \mathrm{mph} ; S=30 \mathrm{ft}$; vehicle in Lane 3.

## Effect of Vertical Displacement

With a perfectly flat cross section, the top of the sign will be a distance equal to the depth of the sign panel plus its mounting height above the pavement. This vertical component has been ignored in the preceding computations. If, however, the sign is installed in a cut section, this vertical displacement can become significant. Figure 64

shows a sign installed on a $4: 1$ side slope beyond a $12-\mathrm{ft}$ shoulder. The elevation of the top of the sign can be computed from

$$
\begin{equation*}
h=D+2.5+(S+W-12) / 4 \tag{62}
\end{equation*}
$$

For sign 7 of the Interstate Manual (93), previously used as an example, $D=15.5 \mathrm{ft}$ and $W=$ approx. 20 ft . If $S=30 \mathrm{ft}$, as previously used, $L$ will be 27.5 ft above the pavement (ignoring any effect of the pavement crown or cross slope). If the driver's eye height is taken as 3.75 ft (21) the effective height of the top of the sign above the driver's eye is 23.75 ft . In the vertical plane, the angle of clear vision, $\theta_{v}$, is less than it is in the horizontal plane. Matson et al. (9) state that $\theta_{v}$ is $1 / 2 \theta$ to $2 / 3 \theta$, which would give a value of about $6^{\circ}$. The same analysis as previously used results in

$$
\begin{equation*}
L H=\sqrt[2]{\left[t V+(h-3.75) \cot \theta_{v}\right]^{2}+(h-3.75)^{2}} \tag{63}
\end{equation*}
$$

Using the values previously derived (see Eq. 59 and dropping the second term) this reduces to
$L H=(2.17+1.94) 117+(27.5-3.75) \cot 6^{\circ}=707$
This indicates that, for this set of parameters, the horizontal displacement is controlling. Because ( $h-3.75$ ) $\cot \theta_{v}$ increases in proportion to $W\left(\cot 6^{\circ} / 4\right)$ (Eq. 62) and because this is always smaller than $W \cot 10^{\circ}$ (Eq. 59 modified for the line of clear vision measured to the right edge of the sign) the horizontal displacement will control.

## Other Considerations

Although this is true for daylight conditions, it does not necessarily hold at night. The previous discussion under "Sign Design for Night Legibility" indicates that there is a considerable decrease of luminance for signs, illuminated by headlights only, as their elevation above the pavement increases. This is especially the case for lowbeam use. Figure 65 shows the combined effect of horizontal and vertical displacement on luminance. The curves shown are for a $20-$ by $12-\mathrm{ft}$ sign with a horizontal offset of 30 ft measured to the left edge of the sign. These curves should be examined in conjunction with Figure 8, to evaluate the effect on required letter size.

Superimposed on the graph is a horizontal line which, after Allen et al. (133), indicates the luminance, in
foot-lamberts, required to obtain the equivalent of daylight ( $50 \mathrm{ft} / \mathrm{in}$.) legibility. The effect of increasing lateral displacement can also be judged by referring to Figure 18 which shows the effect on luminance of increasing horizontal displacement.

The discussion so far has dealt with only one consequence of the lateral displacement of signs: changes in required minimum letter height due to changes in the geometry of the line of sight. There is, however, another effect of horizontal curvature that must be considered. The driver uses all available visual cues to satisfy his need for information about the upcoming alignment of the road on which he is driving. At night, and especially in rural surroundings, such visual cues may be scarce. A


Figure 65. Sign brightness-effect of combined vertical and horizontal displacement.

TABLE 27
SAMPLE COMPUTER RUN FOR DETERMINING REQUIRED LETTER SIZE
degree of curve - -5.8 Left

#  

degree of curve - -4.5 LEFT
 10 degrees at point of beginning Legibility

DEGREE OF CURVE - -4.0 LEFT

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| W | 3 | 4 | 5 | 6 | 7 | 8 | $\bigcirc$ | 10 | 11 | 12 | 13 | 14 | 1 |
| 10 | 12 | 12 | 13 | 13 | 14 | 15 | 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 12 | 12 | 13 | 13 | 14 | 15 | 15 | 0 | 0 | $\bigcirc$ | 0 | 0 |  |
| 29 | 12 | 12 | 13 | 14 | 14 | 15 | 15 | 0 | 0 | 0 | 0 | 0 |  |
| 25 | 12 | 13 | 13 | 14 | 14 | 15 | 16 | 0 | 0 | $\square$ | 0 | 0 |  |
| 34 | 12 | 13 | 13 | 14 | 15 | 15 | 16 | $\square$ | 0 | $b$ | $b$ | 0 |  |
| 35 | 12 | 13 | 13 | 14 | 15 | 15 | 16 | 0 | 6 | 6 | 0 | 0 |  |
| 40 | 12 | 13 | 14 | 14 | 15 | 15 | 16 | 5 | 9 | $\square$ | 6 | 0 |  |
| 45 | 12 | 13 | 14 | 14 | 15 | 16 | 16 | i) | 0 | 0 | 0 | 0 |  |
| 54 | 13 | 13 | 14 | 14. | 15 | 16 | 16 | 0 | 0 | 0 | 0 | - |  |
| 55 | 13 | 13 | 14 | 15 | 15 | 16 | 16 | 0 | 9 | is | 0 | 6 |  |
| 64 | 13 | 14 | 14 | 15 | 15 | 16 | 17 | - | n | 1 | - | 0 |  |
| A Value | Or ${ }^{\text {a }}$ | DEN | S | AT | $E$ |  |  |  | Exce |  |  |  |  |

io degrees at point of beginning legieility
DEGREE OF CIJRUE - - 3.5 LEFT
$W$
18
15
20
25
30
35
40
45
50
55
64
degree of gurve - -2.0 Left

| 3 | 4 | $S$ | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :--- |
| 12 | 13 | 14 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 18 | 19 |
| 12 | 13 | 14 | 14 | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 19 |
| 13 | 28 |  |  |  |  |  |  |  |  |  |  |
| 13 | 13 | 14 | 15 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 19 |
| 13 | 13 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 18 | 19 | 20 |
| 13 | 14 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 19 | 19 | 20 |
| 13 | 14 | 14 | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 20 |
| 13 | 14 | 15 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 20 |
| 14 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 18 | 19 | 20 | 20 |
| 14 | 14 | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 20 |
| 14 |  |  |  |  |  |  |  |  |  |  |  |
| 14 | 14 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 19 | 20 | 21 |
| 14 | 15 | 15 | 16 | 17 | 17 | 18 | 18 | 19 | 20 | 20 | 21 |

degree of curve - -1.5 LeFt


DEGREE OF CURVE - -1.0 LEFT

|  | N |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| W | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 10 | 13 | 14 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 18 | 19 | 26 | 23 |
| 15 | 13 | 14 | 14 | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 28 | 21 |
| 28 | 13 | 14 | 15 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 26 | 21 |
| 25 | 14 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 18 | 19 | 26 | 20 | 21 |
| 36 | 14 | 14 | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 21 |
| 35 | 14 | 15 | 15 | 16 | 16 | 17 | 18 | 15 | 19 | 20 | 26 | 21 | 21 |
| 40 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 19 | 19 | 210 | 20 | 21 | 22 |
| 45 | 14 | 15 | 15 | 16 | 17 | 17 | 13 | 19 | 19 | 26 | 21 | 21 | 22 |
| 59 | 15 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 21. | Sis | 21 | 21 | 22 |
| 55 | 15 | : 5 | 16 | 17 | 17 | 18 | 18 | 19 | 20 | 80 | 21 | 22 | 22 |
| 60 | 15 | 16 | 16 | 17 | 18 | 13 | 19 | 19 | 20 | 21 | 21 | 22 | 92 |

degree of curve - -0.5 Left

|  | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :--- | :--- |
| 10 | 13 | 14 | 15 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 20 | 21 |
| 15 | 14 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 20 | 21 |
| 20 | 14 | 14 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 19 | 20 | 21 | 21 |
| 25 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 18 | 19 | 20 | 20 | 21 | 21 |
| 30 | 14 | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 21 | 22 |
| 35 | 15 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 19 | 20 | 21 | 21 | 22 |
| 40 | 15 | 15 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 20 | 21 | 22 | 22 |
| 45 | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 21 | 22 | 22 |
| 50 | 15 | 16 | 17 | 17 | 18 | 15 | 19 | 20 | 20 | 21 | 21 | 22 | 23 |
| 55 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 20 | 21 | 22 | 22 | 23 |
| 60 | 16 | 16 | 17 | 18 | 18 | 19 | 19 | 20 | 21 | 21 | 22 | 23 | 23 |

DEGREE OF CURVE - -3.0 LEFT
DEGREE OF CURVE - D TANGENT SECTION


Degree of cuíve - -2.5 Left
DEGREE OF CURVE - G.S FIGHT

$\begin{array}{rrr}3 & 4 & 5 \\ 12 & 13 & 13 \\ 12 & 13 & 13 \\ 12 & 13 & 14 \\ 13 & 13 & 14 \\ 13 & 13 & 14 \\ 13 & 13 & 14 \\ 13 & 14 & 14 \\ 13 & 14 & 14 \\ 13 & 14 & 15 \\ 14 & 14 & 15 \\ 14 & 14 & 15\end{array}$
6
14
14
14
14
15
15
15
15
15
15
16 7
15
15
15
15
15
15
16
16
16
16

16 | $N$ |  |
| ---: | ---: |
| 15 | 9 |
| 15 | 16 |
| 15 | 16 |
| 16 | 16 |
| 16 | 16 |
| 16 | 17 |
| 16 | 17 |
| 16 | 17 |
| 15 | 17 |
| 17 | 17 |
| 17 | 17 | 16

16
17
17
17
17
17
17
1
1 11
17
17
17
17
18
18
18
18
18
18
10 12
18
18
18
18
18
18
19
19
19
19
19 13
18
18
19
19
19
19
19
19
20
20
29 14
19
19
19
19
19
20
26
20
20
20
20
15
10
20
20
20
20
20
20
20
21
21
21
21

10
19
19
20
20
21
21
21
22
22
23
23

$$
\begin{aligned}
& 11 \\
& 20 \\
& 20 \\
& 21 \\
& 21 \\
& 21 \\
& 22 \\
& 22 \\
& 22 \\
& 23 \\
& 23 \\
& 24
\end{aligned}
$$


large sign, especially if illuminated or if the background is reflectorized, may be the only such cue, or at least the most prominent one. The driver, on the basis of past experience, will have an expectancy that the road will pass close by a sign when that sign is first perceived. If the sign is displaced laterally to an appreciable extent, it may tend to suppress an intervening horizontal curve or indicate a curve when in fact there is none. The possibility of such deceptive cues must be kept in mind when a decision is made to displace a sign and appropriate measures are taken. In all such cases, it is suggested that delineators be installed from the point of first perception to a point past the sign location.

Additional consequences of increased lateral displacement of signs lie in the area of economics. Right-of-way, construction, and maintenance costs will all increase as the result of larger signs, located farther from the roadway. Furthermore, available sign locations will be sharply limited due to the increased possibility of topographic restraints and because the line of sight will increasingly
fall outside the traveled way, thus raising the possibility of interference by piers, side slopes, and similar intrusions adjacent to the road.

The relationships indicated so far have been derived by strictly analytical means, although some of the parameters, such as divergence angle, visibility distance, and the required level of illumination for night visibility, are derived from previous empirical investigations. Empirical validation of these relationships is still needed. Partial validation of the qualitative concept, decreasing visibility with increased lateral offset, is given by a recent Connecticut study (160). Although the study was limited to tangent sections * and the effect of the divergence angle could not be evaluated because (1) the test driver expected the sign and knew he was supposed to read it, and (2) the absence of all other traffic from the test section allowed the driver to take his eyes off the road with little potential penalty, the study was still able to conclude that "results indicated that an increased legend size was necessary with increased offset distance to retain original legibility distances."

This discussion is not intended to diminish the undoubted importance of clear recovery areas and the reduction in the potential of vehicle-sign collisions. What it does try to do is point to some of the consequences of the removal of signs immediately adjacent to the roadway. The sign designer must be alert to the potential effects outlined herein and assure himself that signs are installed so as to be legible. This will require adequate letter sizes and a check that, during the entire time when the sign is to be read, it actually falls within the cone of normal vision. If this condition cannot be met, a different sign position, a change in message to reduce reading time, or the use of breakaway posts closer to the pavement should be considered.

[^21]
## CHAPTER FOUR

## APPLICATIONS AND IMPLICATIONS

The hierarchy of needs and the principal factors underlying the transmission, reception, and processing of information are combined, in Appendix H , to form a systematic approach to assuring that these needs are met in any new information system. The actual introduction of any new information system must be evolutionary and gradual. The identification and analysis of system elements and their interfaces has proceeded to the point where the impact of
this synthesis on the existing information can be analyzed, and necessary departures from existing practices can be indicated.

For purposes of this analysis, the existing information system is that defined by the Manual of Uniform Traffic Control Devices for Streets and Highways (92) and the Manual for Signing and Pavement Marking of the National System of Interstate and Defense Highway (93) including,
where applicable, official changes and interpretations.* This represents an idealized situation that probably cannot be found exactly in any real-life situation, even in states that have adopted these manuals as official state standards (e.g., Maryland). There is even less likelihood of finding this exact system, without changes or additions, in those jurisdictions, represented by the great majority of states, that have adopted their own, distinct manual.

However, even though individual states and their subdivisions may differ in the treatment of specific situations or in the application of specific information aids, the difference is one of degree rather than one of kind; the basic approach and emphasis of the manuals can be considered as exemplifying current practice.

The impact of the proposed system on existing practices is discussed separately for in-trip and pretrip information sources. The latter category concentrates on problems in the field of mapping and in driver training and testing in map-reading skills.

The two areas selected for discussion do not encompass all implications of the proposed information system. For example, a shift in emphasis from destination-type signing to route-type signing (as discussed in Appendix E) would require extensive public education using mass-media communication to motivate drivers to do their trip planning in these terms. Taking full advantage of driver's expectancies implies not only knowledge of these expectancies, but also the existence of a feasible method of-structuring or changing expectancies on a population basis. Much basic research is required in the areas of the nature of expectancies, the probability distributions of expectancies concerning individual aspects of the highway system, and optimum methods of manipulating expectancies. The list of implications could be extended; however, it is sufficient to realize that, just as the information system is a subsystem of the highway system, the highway system, in turn, is a subsystem of the technological and socio-economic organization of societies. Consequently, changes in one subsystem will result in repercussions throughout the larger systems.

## IN-TRIP SOURCES

## Formal Aiding

Although all sensory inputs furnish information to be processed by the driver, the concept of information system design is usually equated only with the arrangement of "formal" information aids. In comparing two information systems the first step is to compare the "formal" parts of each system.

The level of performance concept and the consequent hierarchy of information needs, developed in Chapter Two, results in classifying needs into three major categories with subdivisions in each: micro needs, situational needs, and macro needs; the category of road needs serves as the transition between micro and situational needs. In standard traffic engineering practice, information aids (mainly signs)

[^22]are grouped into three main functional classifications: regulatory, warning, and guide. These are based on the role of the sign in meeting specific needs. In current formal traffic engineering practices, signs are generally located to satisfy individual needs, regardless of other coexisting information needs. The Manual (92) describes the application of each sign individually, except, of course, for complementary or auxiliary signs such as junction assemblies and advisory speed plates. Some attention is given to spacing between signs, especially directional signs, and the possibility of insufficient space for sign placement is recognized. However, strict adherence to the manual will not result in a different treatment of a given information need when it exists by itself or when it is combined with others. (This discussion deals with formal, codified, signing practices. Most experienced traffic engineers have acquired an operational understanding of the possibility of signal overload and the necessity to pick and choose without a full comprehension of the underlying human factors principles.)

Table 28 gives the category of information needs satisfied by standard signs. This satisfaction can be either direct (D) or indirect (I). Needs can be indirectly satisfied by an inference or deduction that the average driver would normally and automatically make on seeing a sign.:" Table 28 indicates that considering direct satisfaction alone, the three categories of signs can be arranged in a rough qualitative order of descending primacy, ranging from warning through regulatory, to guide signs. However, when the indirect satisfaction of needs is considered, this primacy order is somewhat diluted, although it is still valid. It can also be seen that information needs satisfied inferentially are frequently of higher primacy, for a given sign, than information needs satisfied directly.

Inference and deduction are subjective in nature, and the ability to derive information depends not only on an individual driver's experience, education, and reasoning ability, but also on the kind and amount of quasi-formal and informal aiding available to help in the deduction. The most important element in determining a driver's ability to satisfy information needs by inference is the validity of the direct information transmitted by the sign. In this context, the term validity means the truth and applicability of the sign message.

A driver whose training and experience have led him to expect that the lesser of two intersecting roads will be stop-controlled, and that stop control will be used only within a relatively narrow range of traffic volumes, will, therefore, infer, as he approaches a stop sign in his direction of travel, that the crossroad for which he is stopping is more important than the road on which he is traveling and, therefore, carries heavier traffic. Because, through informal aiding (direct visual observation of traffic), he has already been able to make a qualitative estimate of traffic on the road on which he is traveling, he can now make a qualitative estimate of traffic on the crossroad. This estimate will influence his gap acceptance behavior and general response to the sTop regulation.

However, if the stop message were invalid (i.e., if

[^23]TABLE 28
CLASSIFICATION OF STANDARD SIGNS IN ACCORDANCE WITH
HIERARCHY OF INFORMATION NEEDS

| No. (1) | Lesend | Micro |  |  | Sifuational |  | Macro |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Vehicle | ARI | Road | Traffic | ARI | Direct. | Service | ARI |
| R1-1 | STOP |  |  | $I^{(2)}$ | $D^{(3)}$ |  | I |  |  |
| R1-2 | YIELD (4) |  |  | I | D |  | I |  |  |
| R2-1 | SPEED LIMIT ${ }^{(4)}{ }^{(5)}$ |  | D |  | I |  |  |  |  |
| R2-5 | SPEED ZONE AHEAD ${ }^{(5)}$ |  | D |  |  |  | I |  |  |
| R3-1 to 4 | TURN PROHIBITION SIGNS |  |  |  | I | D | I |  |  |
| R3-5 to 8 | LANE USE CONTROL |  |  | D | 1 |  |  |  |  |
| R4-1 | DO NOT PASS |  |  | I | I | D |  |  |  |
| R4-2 | PASS WITH CARE |  |  |  | 1 | D |  |  |  |
| R4-5, 6 | UPHILL TRAFFIC LANES SIGNS |  |  | I | I | D |  |  |  |
| R4-6 | TRUCK LANE 500 FEET |  |  | D | I |  |  |  |  |
| R4-7 | KEEP RIGHT |  |  | I | I | D |  |  |  |
| R5-1 | DO NOT ENTER |  |  |  |  | D | I |  |  |
| R5-2 | NO TRUCKS |  |  |  | I | D | D |  |  |
| R5-3 | PEDESTRIANS PROHIBITED |  |  |  | I |  |  |  |  |
| R6-1, 2 | ONE WAY ${ }^{(5)}$ |  |  | I | I | D |  |  |  |
| R7 $710-1$ | PARKING AND STOPPING SIGNS KEEP OFF MEDIAN |  |  | I | I | D |  |  |  |
| R10-2 | ROAD CLOSED |  |  |  |  | D | I |  |  |
| R10-3 | ROAD CLOSED 10 MILES AHEAD |  |  |  |  | D | I |  |  |
| R10-4, 5 | WEIGHT LIMIT SIGNS |  |  | I | I | D | I |  |  |
| W1 | TURNS AND CURVES SIGNS |  | I | D | I | I |  |  |  |
| W2 | CROSS AND SIPE ROAD SIGNS | - |  | D | I |  | I |  |  |
| W3-1 | STOP AHEAD ${ }^{\text {P }}$ |  |  | I | I | D |  |  |  |
| W 4-1 | MERGING TRAFFIC |  |  |  | D |  |  |  |  |
| W 4-2 | PAVEMENT WIDTH TRANSITION |  |  | D | I |  |  |  |  |
| W7-1 | HILL | I |  | D |  |  |  |  |  |
| W8-1, 2 | BUMP OR DIP |  |  | D |  |  |  |  |  |
| W8-3 | PAVEMENT ENDS |  |  | D |  |  |  |  |  |
| W3-4 | SOFT SHOULDER |  |  | D |  |  |  |  |  |
| W8-5 | SLIPPERY WHEN WET | D |  |  | I |  |  |  |  |
| W9-1 | SCHOOL ${ }^{(11)}$ |  |  |  | D | I | I |  |  |
| W10-1, 2 | RIR CROSSING SIGNS |  |  | D | I |  |  |  |  |
| W11-1 | TIRUCK CROSSING |  |  | D | I |  |  |  |  |
| W12-1 | DOUBLE ARROW |  |  | D | I |  |  |  |  |
| W12-2 | LOW CLEARANCE |  |  | I |  | D |  |  |  |
| W13-1 | ADVISORY SPEED |  | D |  | I |  |  |  |  |
| M1-1, 2 | ROUTE MARKER |  |  |  |  |  | D |  |  |
| M2-1, 2 | JUNCTION MARKER |  |  | I | I |  | D |  |  |
| M3-1, 2 | ADVANCE TURN ARROW |  |  | I | I |  | D |  |  |
| M4 | DIRECTIONAL ARROW |  |  |  | I |  | D |  |  |
| M5 | ALTERNATIVE ROUTES |  |  |  |  |  | D |  |  |
| M5 | CARDINAL DIRECTION MARKER |  |  |  |  |  | D |  | D. |
| M7-1 | TRAILBLAZER |  |  |  |  |  | D |  |  |
| D1 | DESTINATION SIGN |  |  |  |  |  | D |  |  |
| D2 | DISTANCE SIGN |  |  |  |  |  | D |  |  |
| D3 | STREET NAME SIGN |  |  |  |  |  | D |  |  |
| D4-1 | PARKING AREA |  |  |  |  |  | I | D |  |
| E1-1 | "EXIT" |  |  | D | I |  | I |  |  |
| E1-2 | "EXIT" (WITH DESTINATION) |  |  | D | I |  | D |  |  |
| E1-3 | EXIT DIRECTION |  |  | D | I |  | D |  |  |
| El-4 | " THRU TRAFFIC" |  |  |  |  |  | D |  |  |
| E2 | EXIT DIRECTION |  |  | D | I |  | D |  |  |
| E3-1, 2 | ADVANCE SIGN |  |  | I |  |  | D |  |  |
| E4 | NEXT EXIT |  |  |  |  |  |  | I | D |
| E5 | REST AREA |  |  |  |  |  |  | D |  |
| E6, 7 | SERVICE SIGNS |  |  |  |  |  |  | D |  |

NOTES: (1) Numbers refer to "Manual of Uniform Traffic Control Devices" (92)
(2) I - Inferential Satisfaction of Information Need
(3) D - Direct Satisfaction of Information Need
(4) Includes Special and Night Speed Limits (R2-2, R2-3)
(5) Also End -- Mile Speed (R2-6)
(6) Also Two Way Traffic Ahead (R6-3) and End One Way (R6-4)
(7) Also No Parking On Pavement (R8-1)
(8) Pedestrian Crossing (R9-1 to 7) Omitted
(9) Also Yield Ahead (W3-2) and Signal Ahead (W3-3)
(10) Applies also to all signing denoting Changes in Cross-Section such as W5-1, W5-2, W5-3, W6-1, W6-2
(11) Also School Crossing (W9-2)
traffic volumes were either so low that no control should have been used, or so high that the proper control should have been a traffic signal)* the inferences made will be incorrect and the driver's need for information concerning traffic volumes on the cross street will not be satisfied. If the same situation recurs often enough, the driver will cease to make proper inferences in this particular situation and a valuable aiding technique will have been lost.**

Likewise, inferences can be drawn from the absence of formal aids-for example, the inference that in the absence of a CURVE sign there will be no changes in horizontal alignment of a severity to require abrupt or extreme changes in vehicle operation. Other inferences are not so obvious and may, in fact, be erroneous even through based on valid sign messages. A good example of this, described by Schoppert et al. (96), is the problem of "negative reasoning"; that is, if a destination or route is not specifically mentioned, it cannot be reached by a certain route.

From the previous discussion two principles emerge: (1) the importance of any sign depends on its position on the primacy scale relative to the highest ranking information need that is satisfied, either directly or inferentially, and not only on the information supplied directly, and (2) the sign message validity is of extreme importance. Ad hoc solutions to traffic control or information transmission problems, using "invalid" sign messages, might appear to be feasible when only the direct effect is considered. However, the effect of thls use on the inferential satisfac tion of information needs, at the specific location as well as in the long-range structuring of expectancy, must be considered.

Implications of this study for the existing signing system discussed so far have dealt (1) with the importance of considering all coincident information needs when trying to satisfy a specific need, and (2) with the importance of considering inferential satisfaction of needs. That inferences can be made from both the presence or absence of explicit information must be considered in developing a total information display scheme. A corollary implication involves the importance of evaluating the possible effect of any aiding method proposed for the satisfaction of a specific need on the satisfaction of information needs higher on the primacy scale, or even on the creation of new needs.

Generally, signs in the warning category satisfy information needs higher on the primacy scale than the needs satisfied by signs in the regulatory or guide category. This is modified by the high degree of inferential need satisfaction of the apparently lower ranked signs. Any case of conflict between using a warning-type sign to satisfy a specific need and a regulatory-type sign to satisfy another specific need (presumably lower on the primacy scale) should be resolved in favor of the warning-type sign.

At this point, other factors must be considered. The information aiding process does not take place in a vacuum

[^24]but, rather, in a real-life situation where the degree of freedom of action is limited by legislative action, administrative regulations, and executive opinions. These constraints require that definite information needs be satisfied in a certain manner in a particular location, irrespective of the total information need situation or physical conditions. These chosen needs may occur at any place on the primacy scale, or may even be completely off the scale. That is, they may be information needs not pertinent to the driving task as defined in previous sections. These range from no littering admonitions (a laudable social goal, but of low primacy for the safe and expeditious completion of the driving task) to more or less covert political and commercial advertising. It is essential that this type of signing be reduced as much as possible and eliminated in areas of high information need. When used, these signs should be reserved for low-need areas where they may be used to maintain a high vigilance level.

Whenever there is a choice of a location, in time as well as in space, at which a specific information need can be satisfied, the location with the lowest total information needs should be selected. Information needs with a wide range of locations at which they can be satisfied are those covered by general regulatory signs. These include all signs, exclusive of statutory speed limits, that contain regulations applicable to the entire highway system or to a major functional part thereof, such as expressways. It is atrongly recommended that this need satisfaction be regulated to the pretrip phase where high primacy needs are at a minimum.

This is already being done to a certain extent. The information contained on general regulatory signs, ranging from no littering to expressway exclusion signs, special school-bus traffic regulations, and other repetitions of laws and regulations, is presumably already known by the driver. The redisplay of this information on the highway is thus in the nature of a reminder.* Certain regulations are considered so basic, and overlearned, by the driver that no reminder is ever considered necessary. Signs are not erected with the message do not drive on sidewalk or drive on the right side.** Reminder information on other regulations may be displayed depending on a subjective evaluation of their need. This evaluation is usually made on the basis of actual or expected violation rates. Insofar as regulations applicable to the entire highway system are concerned, it is strongly recommended that: (1) driver training and licensing procedures be changed to bring all of these regulations to the same level of overlearning as the examples cited, and (2) the use of this type of sign be discontinued, except for the purpose of raising the vigilance level in low-signal areas.

The case is somewhat different for regulations applicable only to individual functional parts of the highway system such as freeways, parkways, and residential streets. Although the information of these regulations can (and

[^25]should) also be furnished in the pretrip phase with no further reminder necessary, the driver still is faced with the need to know which part of the highway system he is traveling on or is about to enter. This need cannot always be met unequivocally by informal aiding-that is, by the perception of highway type, cross section, and alignment.

The various specific information needs as to the exact applicability of individual regulations to highway locations can be met by inference. The ability to make this inference can be developed as part of the driver training and licensing procedure when the potential driver is informed of the regulations applicable to each defined part of the highway system. * The information need "Type of Road" is included in the inventory of needs (Chapter Two), and it is recommended that, by the use of chunking, this need be combined with the need to know applicable regulations. A possible approach to this can be found in the proposed revisions to the United Nations Protocol on Road Signs and Signals (98) that reads

> Sign E-15 (a symbolic sign) shall be placed on the approach to a road to show that it is a motorway ** and that, consequently, the traffic rules to be observed on it are those applicable to motorways. Sign E-16 (a symbolic sign) shall be placed at the exit from a motorway to show that the motorway ends.

Several preceding sections of this report deal with factors influencing the transmission and reception of information on the visual channel. Although examples used are drawn mainly from directional signing applications (satisfaction of macro needs), all the general principles derived in those sections apply equally to regulatory and warning signs (satisfaction of micro and situational needs). Except for these principles, this report makes no further recommendations for changes in current practice in the design of this type of sign. A considerable body of knowledge, derived from formal academic research and empirical results from actual sign installations both in the United States and elsewhere,*** exists in this field and is constantly being increased. With few exceptions, the principles and procedures for the satisfaction of information needs, derived from this study, can be implemented by using current standard signing with the realization that research results, as mentioned, will find an evolutionary application within the system as the studies are completed.

Up to now, the implications of the proposed information system on current practices, and the recommendations following therefrom, have been stated in the form of general principles. These principles deal with over-all

[^26]approaches to providing information: display, choices among competing alternatives, and minimization of the necessity to satisfy needs en route. However, when one analyzes the implications of the proposed system on the satisfaction of macro needs (guide and information signs), more specific and far-reaching conclusions can be drawn and recommendations made.

Appendix E contains a discussion of the problem of satisfying macro needs, with specific recommendations on what information is to be shown where and, to a lesser extent, how. The implications for current practices naturally involve all those areas where recommended practices differ from current ones. To review, the change in emphasis from making directional signing a tool for destination finding to making it a tool for route following involves changes in the following areas:

1. Route designations, both name and number.
2. Mileposting methods.
3. Interchange numbering methods.
4. Treatment of highway links in urban networks.
5. Location and legend of directional signs.
6. Signing for services.

The implications of the proposed method of satisfying macro needs on the trip planning process are discussed subsequently in "Pretrip Sources."

## Quasi-Formal and Informal Aiding

Quasi-formal and informal aiding were defined as the reception of information from sources whose primary purpose is not the transmission of information. The differences between quasi-formal and informal consist of the degree to which information transmission was a consideration in the design of the aiding device.

No specific recommendations concerning the use of these aiding devices are made here except insofar as the example, pavement joints, cited in the general discussion of aiding, led to a specific recommendation.

This report stresses the importance of considering the total information needs of the driver at all times, rather than attempting to satisfy individual specific needs with specific means. Any consideration of total information needed must consider the total information available. The total information needs of the highway user are met by increasing, decreasing, or otherwise altering the information available.

The total information available includes all quasiformal and informally aided information as well as the information content of formal aiding devices. The major implication in this area is, therefore, to stress the importance of becoming aware of quasi-formal and informal aiding techniques, and to evaluate all the possibilities of information transmission inherent in existing quasi-formal and informal aiding before proceeding to the design of formal aiding devices. This includes not only the information transmitted by these existing nonformal aids but also the ways in which this information can be changed by manipulation.

This implies that the officials responsible for satisfying
information needs must go far beyond the limits traditionally assigned to this discipline within the organization of highway engineering. Highway location, alignment, design and construction, landscaping, zoning and other land-use controls, commercial radio broadcasting, and advertising controls are only a few of the aspects that must be considered to satisfy the total highway system information needs.

## PRETRIP SOURCES

The human factors analysis has indicated that the driver must receive, process, and act on information transmitted by several sources, including the vehicle, road, traffic, signs, signals, and landmarks. Frequently, if not always, information from all these sources competes simultaneously for the driver's attention. The driver must constantly select from this multitude of data the information that is most relevant to the successful performance of his driving task. Further, the driver must ignore some important information in order to act on information that is relatively even more important. The ability to select the relevant data and establish priorities depends largely on the driver's education, experience, and pretrip planning. Incorrect decisions can have severe repercussions. Drivers should know that the decision to ignore information such as a rapidly decreasing gap to look at a sign indicating emergency services can lead to a collision.

Primacy is one of the principles derived and discussed in Chapter Two. It was found that directional information usually has the lowest priority when various kinds of information compete for the driver's attention. This implies that whenever directional information is given at the same time as critical vehicle, road, or traffic information, it is the competing directional information that should be ignored by the driver. However, the driver who is unfamiliar with the road being traveled or the precise route to his destination cannot be depended on to make the right decision about which information to attend to and process. The driver who has not made adequate pretrip preparation does not know what to expect in the way of directional signing. Also, he does not know what macroperformance information he needs in-trip. Under these circumstances, he is required to look not only at signs that are relevant to his trip, but also at other directional signs to determine whether they are relevant. Many directional signs are placed in or near complex interchanges where the need for other, more important, information is at its peak. It is at these complex interchanges that the accident hazard is greatest.

Any solution requires an approach that considers not only the driver at the moment of decision, but also elements of his trip preparation. If what the driver knows about specific aspects of his trip, before he takes it, is fully understood, it becomes easier to relieve the decision-making load at any point.

According to McGill (82) :
Any technique which simplifies . . . interactions [between vehicle, operator and the social physical environment] might . . . be expected to improve efficiency and safety. The use of population expectancies in system
design is such a technique. In both human engineering and psychological literature there is evidence that tasks which conform to thesc expectancics tend to be per. formed faster and more accurately.
Relating this to the problem at hand means that if the driver knew a priori what to expect at an interchange in terms of road configuration and what direction he should take, he would be better equipped to handle all the information that was presented to him when he got there.

## Mapping

The analysis and discussion of the macroperformance needs in Appendix $E$ emphasizes, that

> . macro needs, being low on the primacy scale, must yield to micro and situational needs and, therefore, should be satisfied, to the greatest extent possible in areas of minimum micro and situational demands. The pretrip phase, where only macro needs exist, should therefore be used to the greatest extent possible.

This places a great burden on pretrip preparation. In the absence of an automated direction-finding system; the driver must know where he is going and how he is going to get there before he leaves home. This places a great deal of system reliance on the adequacy of maps, which frequently are the only aid the driver has in his trip preparation.

Maps can and should prepare the driver to deal effectively will most elements of macroperformance and those elements of situational performance that are necessary to implement route following. The discussion of expectancy (Chapter Two) indicates the importance of presenting that information to the driver-in-transit that he expects to see. It is also indicated that driver expectancy can be structured. That is, the driver can be prepared, at an earlier point in time, for what to expect to see on the road. The purpose of maps, in addition to the obvious purpose of assisting the driver in route planning, is to prepare the driver for his trip by structuring his expectancies.

One of the major drawbacks of present-day maps is that they fail to accomplish the second purpose. To structure driver expectancy, there must be a high correlation between what the map indicates on the highway and what is, in fact, on the highway. The driver who consulted a map of Long Island, N.Y., might conclude after some study that there will be a sign for Farmingdale somewhere on the Long Island Expressway. There is no way, at present, for the driver to know that there is no sign for Farmingdale on that highway. If some places are signed for, the driving public should have a way of determining which places are and which places are not. It should be clear from reading the map that route 110 south is what the driver should look for to get to Farmingdale from the Long Island Expressway.

To prepare the driver to deal effectively with those elements of the situational performance that are necessary to implement route following, the map should tell the driver something about the road on which he will be traveling. Specifically, because information needs are usually at their peak at or near interchanges, some of the information load will be taken off the driver if he knows
a priori the configuration of the interchange he is about to enter. This information must be reinforced by signs on the highway, but its primacy place is on the map.

The discussion in Appendix $\mathbf{E}$ indicates that en-route macroperformance information should be transmitted to correspond to a route-oriented trip-description system. This means that, as a rule, destinations will not be signed for. If en-route destination macroperformance information emphasizes route numbers and names, it is incumbent on maps to show clearly how destinations can be reached by using specific routes characterized by their numbers and names. Names of geographic areas or political subdivisions on maps must be placed so that no ambiguity exists relating to which routes or exits serve which area. It is equally important that highway numbers and names are prominently located on the map. If the Kennedy Expressway is I-94 in one place and Illinois 194 at another, and if New York 25 is Jericho Turnpike at one place and Middle Country Road at another, it is incumbent on the maps of these areas to prepare the driver for these situations.
To achieve maximum use, it is important that symbology be consistent from map to map. AASHO recognized the need for uniform symbology in maps as early as 1926 , and in 1962 published its current recommendations in this area (102). However, as documented in Appendix G, there has been only partial incorporation of the AASHO recommendations on uniform symbology into state highway maps presently being published. Although this study was not extended to oil-company maps,* it is believed that their acceptance of these recommendations does not exceed that of the official state organizations. Although not much is known about the map-reading skill of the driving population, it can be assumed that uniformity in maps and symbology can only serve to increase map-reading skill level.

A thorough investigation of mapping concepts, techniques, and procedures is considered an important area for future research.

## Demand System Mapping

A major precept in most operator informational systems is that the operator should receive all information required to perform his task, and no more. At first glance, this seems to be a reasonable goal for the highway system. Noise, whether auditory or visual, is an unwanted signal input to the driver, and can only confuse or distract him from the task at hand. However, what is noise for one driver is required information for another-for example, a sign for Boston may be noise for the driver who is going to Chicago, but it is required information for a driver going to Boston. This indicates that the individual driver is the only one who can say which signals are information and which are noise. Without getting into a discussion of technical feasibility, one rather obvious solution is an information demand system, either visual or audio; give the driver nothing unless and until he asks for it.

From a human-factors standpoint, this requires that the

[^27]driver know what he wants to know. This implies a greater dependence on maps and trip preparation. Trip preparation can also employ a demand system. The American Automobile Association (AAA) already operates a demand trip-preparation system. The input to this system is a starting and ending point; the system supplies the rest of the data. To develop an information demand system, the initial phase of the system must be compatible with present highway design and signing. This would give a change by evolution, not revolution. The demand system of AAA seems to be a good starting point.

One feature that oil-company maps have that this system lacks is convenience and availability to all motorists. It seems logical that any change in mapping for motorists' use should have these two features. It should also be free to the motorist.

A feature not found consistently in either the oilcompany maps or the AAA trip maps (but highly desirable) is one that shows the motorist a detailed layout of highway interchanges and intersections. Because there is no standard design for interchanges and intersections, the motorist does not know what he will encounter when he tries to enter or leave the highway. Maps should prepare the driver for the required maneuvers.

Another requirement is greater correlation between maps and highway signs. Route signing at interchanges and exits should also be detailed on trip maps.

This kind of map system allows the motorist to determine on an a priori basis the information available to him on the highway system and, to some degree, makes up for deficiencies in the design of highways and the signing system because the motorist will be better prepared for them.

## Map-Reading Skills

It is evident that the proposed systematic presentation of information with its emphasis on trip preparation represents a severe test for the map-reading skill of the driver. Regardless of how well maps present information to the driver, unless he is able to read and derive meaning from the map content, he will be ill prepared to drive in the highway system. Lack of adequate trip preparation will increase the burden of information needs during the intransit phase of the trip. It is shown elsewhere in this report that the burden on this phase needs to be reduced if the system is to meet the criteria of safety, convenience, efficiency, and comfort. It can be seen then that mapreading ability is one of the key elements in the success of the information system under investigation.

Unfortunately, little is known about how this skill is distributed among the driving population. In the course of conducting this research, the researchers found many people with strong opinions about the public's mapreading ability, but no one who had or knew of any data justifying his opinion. In short, no relevant research has been found that approaches, from any angle, highway map-reading skill. Also, little evidence was found to indicate whether map reading is the subject of either driver training and education courses or a demonstration test for
a driver's license. According to Dr. Charles Hartman,* Head of the Education Division of the Automotive Safety Foundation, ASF is looking into what subjects are important enough to be included in driver education courses. Richard A. Swart of the Public Safety Department of the Automobile Club of Southern California indicated that "Some amount of public school driver education in California touches on map reading, but we don't know anything about length or extent."* Spindletop Research Inc.,* in its preliminary investigation into licensing procedures, has found no state that requires demonstration of map-reading ability to obtain a driver's license. The lack of these programs can be assumed to indicate either a very high level of ability or a very low level of ability. In light of the previously mentioned low opinion of many highway researchers, the assumption is made of a low level of map-reading ability in the driving public.

Two courses of action are available to remedy the situation. Maps can be made simpler to read and people can be trained to read them more efficiently. To achieve maximum results, both of these courses of action should be implemented. The researchers do not agree with the statement (in private conversation with one official of a major map-making company) that today's highway maps are about as good as they can get. Maps can be improved. The researchers also do not agree with the apparent tacit opinion of trainers and educators that map-reading ability is not important enough to be the subject of formal training. And, finally, it is incumbent on each state to ensure that the people to whom licenses are granted are capable of preparing a trip plan by using all means at their disposal. It is emphasized that information needs begin when a driver decides to make a trip-not when he gets in the car and starts the engine.

## PROCEDURAL CHANGES AND PHASING

## Scope of Changes

Radical changes, far more extensive than any proposed as a result of the research reported on herein, are not unknown in the field of highway transportation. Examples include the change, starting in 1964, of almost all the British road signs, reported on by Usborne (103), and more recently and more far-reaching the Swedish change to right-hand driving on 3 September 1967 (104). The change in Sweden was obviously one that had to be accomplished literally in one instant. It was preceded by four years of planning and public education. The change in England, on the other hand, had to be stretched out over a considerable period of time due to budgetary and fabrication limitations. It is now scheduled to take a total of eight to ten years. It is accompanied by an extensive publicity campaign that uses all media of mass communication.** It is estimated that as of July 1967, representing

[^28]the middle of the changeover period, in excess of 30 million publicity items have been produced.*

Both of these change programs are apparently successful. Preliminary reports from Sweden term the changeover "a complete success" (106, 107). In the United Kingdom, the success is not as unequivocal nor as easy to measure. A report of the Road Research Laboratory (108) characterized sign understanding as "not at a high level." In discussing these findings, Usborne points out that studies made of the understanding of the old system, prior to the changeover, also showed low recognition rates for certain signs, and that understanding of the new signs would undoubtedly increase as more signs were placed on the road and additional publicity efforts made.

The two features that these changes have in common, and which undoubtedly were largely responsible for the success obtained, were mass communications and absolute uniformity. Neither of these has ever been used to implement a major traffic engineering change in the United States. Whole-hearted participation of all means of mass communication is the essential prerequisite to the making of any major change in highway communication.

The changes in the system of information presentation and their implications on current practices, as discussed previously in this chapter, have two distinct sets of implications. One set is for the traffic engineer and other officials and agencies engaged in furnishing and displaying information to the driver, including all agencies responsible for any device capable of quasi-aiding, as discussed previously in "Satisfaction of Information Needs." This set of implications includes the recognition of the pertinent human factors and their influence on the selection of information and the methods of displaying it.

Initial implementation of the recommendations of this report will not be obviously apparent to the highway user insofar as the microperformance and situational levels are concerned. This implementation will consist of applying formal aiding techniques (mainly existing familiar signs and markings) and manipulating quasi-formal and informal aiding techniques in accordance with human factors principles such as primacy, expectancy, and spreading. It may be described as the optimum use of present microperformance and situational aiding techniques. Of course, recognition of these principles and of the hierarchy of needs should lead to specific research aimed at improving the design of sign faces. The major impact on the driving public will not occur until the macroperformance information needs satisfaction recommendations of this report are implemented.

## Impact on Driving Public

The motorist operates with a set of expectancies concerning the kind of information and manner of presentation he will encounter en route. Although little is known concerning the exact population distribution of these expectancies, it can safely be assumed that an appreciable portion of the population expects to find detailed directional

[^29]information, in terms of destinations, en route. These people will start on lengthy trips with only the sketchiest trip preparation, and expect to find detailed signing to any part of the globe starting at their doorstep. Actually, they may expect to "pick up a map" to correct what they consider "deficiencies" in signing for their specific destination. The fact that some destinations do appear on signs, and there is no precise method of predicting which destinations these will be, has contributed to structuring this optimistic expectancy.

The proposed method of furnishing directional information is based on the premise that the main purpose of this type of information and the only purpose that appears to be practicable is to enable the driver to execute an a priori prepared, route-oriented trip plan. The driving population must therefore know that such a trip plan is a necessary prerequisite. The population expectancies must be structured to expect this kind of information and no other. Furthermore, this education program must be accomplished, or be well under way, before the changeover is complete.

New drivers may be indoctrinated as part of formal driver training, or, as suggested, by being informed that the body of knowledge implied by the necessity of making a trip plan will be part of the requirement of obtaining a driver's license. Existing license holders will be harder to reach. In many states, license renewal is automatic and can be accomplished by mail or by the use of a professional middleman (such as the "Currency Exchanges" in Illinois). Printed matter can be sent with the new license. However, this is easy to ignore, and the licensing authority would have no feedback of whether the message was received and understood. The proposed mandatory reexamination of all drivers at least once every four years, as announced by the National Highway Safety Agency (109), will, if implemented, make all drivers part of a captive audience to which this indoctrination can be given and feedback obtained.

With older drivers, where this expectancy of destinationtype directional information is deeply seated, iteration of the proposed system once every four years may not prove sufficient. This is especially the case because destinations will not disappear overnight from highways. Apart from the old signs remaining during the necessarily protracted changeover period, there will also be places where destinations appear in the new system. They will be displayed as redundant information, as part of the names of highways and as synonyms for cardinal direction. The complete absence of all destinations from highway signs, which might have hastened the learning process and destroyed the old expectancy, cannot be counted on.

The concerted effort necessary to reach all drivers sufficiently often to structure the new expectancies will have to include all means of mass communication. It must, quoting former Federal Highway Administrator Lowell K. Bridwell (110), ". . . harness the kind of talent that labors to produce eye-catching commercials on television, the intriguing ads in our popular magazines and contemporary graphics techniques. . . ." The European experience shows that a massive advertising effort is required.

Projecting the figures previously quoted for the United Kingdom to United States population and registration figures indicates an effort ranging from 100 million to more than 200 million items.

Full implementation of the new system cannot occur until market research indicates that the product has been sold. A period of four years, such as used in Sweden, may be necessary. During this period, of course, signs being changed for normal reasons (accidental damage, maintenance, new message, etc.) can be designed as part of the new system with, possibly, the old destinations remaining on a supplementary panel or auxiliary sign. Any new sign erected should, of course, be designed in accordance with the principles concerning letter height, brightness, and optimum location derived in this report.

During this initiation period, a concentrated effort must be made to accomplish the changes in mapping, and mapreading skills detailed in the previous section. Here again, the media of mass communication can be helpful, and map availability, map contents, and map-reading skills can be presented as a product to be publicized. If the privately owned mass-communication media are convinced that it is in their interest and the public interest to undertake such campaigns, great progress can be made. Perhaps the metropolitan area maps now distributed by some newspapers (e.g., Chicago Tribune) could be the leaders in presenting the required information in the most comprehensible manner.

The AAA* is aware of shortcomings in existing maps and can be expected to lend its experience to any improvement effort. Budgeting limitations and the difficulty in keeping information up to date have, so far, prevented any major improvements, although pilot studies on improved maps have been made. The AAA's patented strip map system is an excellent example of the kind of routeoriented trip plan mentioned here. The members of the AAA- 12 percent of the driving population (111)-are well-oriented in the use of the recommended type of trip plan.

Because of the restricted availability of trip-planning services of the AAA and other motor clubs, oil companies are increasingly using trip-planning services as promotional devices. With the intense competition prevailing in that industry, it is possible that having the best touring service may become a competitive advantage. (One oil company, Mobil, has made a management decision to have the "best" maps according to information furnished by a commercial map maker.)

## Procedural Changes

Many experienced traffic engineers are already aware of some of the human factors principles developed in this report and are using these in signing work. The major procedural changes required involve the formalization of the suggested design review procedure of Appendix H and the establishment of a system of checks and balances to ensure that the various steps are followed and the required feedback loops are checked. One possible method of

[^30]accomplishing this could be to establish, within each jurisdiction responsible for signing, a position that could functionally be described as "Information Transmission Coordinator." This would require an administrator able to participate in all decisions that affect the total visual environment of the driver, as discussed previously.

It is imperative that all formal and informal procedures and the training of personnel engaged in this work emphasize the human factors principles involved in the reception, processing, and use of information and the importance of considering the totality of the information needs at all times.

Changes in the various manuals will also be required for full implementation of the proposals set forth in this report. One of the prime changes will be to consider letter height and sign position as a design variable depending on local conditions in accordance with the discussion of Chapter Three. Sign face design, and location of directional and service signing should be changed in accordance with the proposals of Appendix E , although it must be emphasized again that the sample sign layouts shown in that section represent only one of many possibilities, and that further research to find the optimum sign face design is required.

Finally, procedures should be changed throughout the entire highway planning, design, and construction process to realize that ". . . the signing, in the final analysis, is an integral part of the highway" (112).

## Phasing

The research reported on in this report did not result in a large body of empirical data capable of immediate application. Rather, the results are in the form of a series of recommendations and proposed solutions to existing problems. Some of these can stand by themselves; others are stated in relatively loose terms and need additional research, to decide on details of application, before implementation is possible. No suggested phasing can, therefore, be expressed in terms of specific dates or specific number of months after initiation. The only thing that can be done is to isolate those recommendations that can be implemented before necessary preconditions are satisfied.

## Immediate Implementation

1. The application of human factors principles and the concept of "total information needs" in the design, installation, and evaluation of all information aids and in the evaluation and manipulation of all potential sources of information.
2. The development of curricula for the teaching of trip planning and map use as an integral part of driver education.
3. Formalization of system application procedures and sign design procedures. Depending on the results of quantitative human factors research, these should be aimed toward maximum use of computer applications.

Second Step Implementation (To be preceded by some of the additional research outlined in Chapter Five)

1. Changes in manuals and other guides to sign design so as to make letter height, brightness, and sign location interdependent design variables.
2. The development of optimum content and display standards for highway maps.
3. Development of a standard optimum sign design for the presentation of directional and service information.

Third Step Implementation (To be preceded by completion of applicable items under the previous two subheads)

1. Initiate mass media publicity and education campaign on trip planning and importance of route-oriented trip plans.
2. Initiate necessary changes in route designation, interchange numbering, and mileage markings as discussed in Appendix E.
3. Develop testing procedures to include trip-planning abilities as part of driver licensing.

## Fourth Step Implementation

1. Initiate directional signing changes to accord with route-oriented trip descriptions.
2. Include trip-planning skills as partial requirement for obtaining new or renewal driver license.
3. Change maps in accordance with results of item 2 under "Second Step Implementation."

## CONCLUSIONS AND SUGGESTED RESEARCH

## DRIVERS' INFORMATION NEEDS AND THEIR SATISFACTION

## Conclusions

The research was conducted in several areas of study. These included the information needs of the driver, the interaction between these needs, the factors affecting transmission and reception of information, and the systematic means of evaluating information presentation. The following conclusions are drawn based on the findings of the reported research:

1. Driver information needs occur throughout the entire driving task, and include pretrip planning.
2. Driver information needs fall into a hierarchy with a distinct primacy relative to satisfying those needs. The hierarchy in the descending order of primacy can be summarized as:
a. Microperformance Information Needs: those associated with the two main tasks of tracking and speed control.
b. Situational Performance Information Needs: those associated with obstacle avoidance and maintenance of the most efficient and safe course in the traffic stream.
c. Macroperformance Information Needs: those associated with trip preparation and direction finding.
3. Use of the primacy concept of information needs is an important requirement of highway information system design. That is, directional (macro) information (lowest on the primacy scale) should not be transmitted when the driver is busy handling micro- or situational performance needs. Application of this concept provides the bridge needed to make driver-needs analysis a formal part of applications of the highway information system.
4. The highway information system must consider all informal and formal information transmission (e.g., pavement and landscaping layout and design and signs and markings, respectively).
5. The basic requirements of the highway information system are:
a. User-centered.
b. Applicable to existing highways.
c. Can serve all drivers at all times.
d. Fail-safe.
e. Compatible and evolutionary.
f. Economically feasible.
6. The basic design principles for the systematic presentation of information to the driver are:
a. Observe the primacy concept of transmitting first things first.
b. Do not overload the driver's processing capabilities.
c. Require the driver to prepare himself by trip planning.
d. Spread the transmission of information to avoid overloading and vigilance problems.
e. Do not surprise the driver-make information transmitted conform to his expectancy.
7. The transmission of information to satisfy the macroperformance (directional) needs can best be accomplished by using visual communications in the following manner:
a. Formalizing and improving driver's trip-planning capability. This includes improvements in mapping to correlate highway information and maps, and a system to make maps readily available to drivers. It would also be desirable to have a means of conveniently storing and using the trip plan in the car. This would serve as a step toward eventual automation of display of routing information in the car.
b. Making maximum use of signs as transmitters by optimizing the use of signs as to location, message content, and design. The major changes in location will result from conforming to the aforementioned primacy and spreading requirements. Major changes in message content result from the emphasis on route following instead of destination.
8. Procedures, and a computer simulation, have been developed for the design of signs under conditions of darkness.
9. A procedure has been developed for information system design review that incorporates driver needs analysis, the concept of primacy, and the use of informal aiding techniques in the design of the sign system.
10. Electronic aiding techniques were found to have their maximum potential use in meeting situational and microperformance needs.

## Suggested Research and Development

The following areas require further research, experimentation, and/or development:

1. Apply and modify/validate the "Information System Review Procedures." This procedure incorporates as a basic part the driver-needs analysis and the concept of primacy. Although this procedure has been partially applied to highway situations, it is essential that it be applied to additional portions of highway to test it under varying conditions.
2. Extend and refine the computer procedure for sign design to include such additional parameters as ambient lighting, headlight glare, multiple-car configurations, superelevation, cross slope, and transition curves. Apply the procedure to a gamut of differing field conditions and vali-
date the simulation results by field photometric testing so as to derive a sign design handbook with nomographic solutions for most common design situations.
3. Extend the mathematical analysis of truck blockage to car and truck distributions actually encountered. Validate results of the analysis by field measurements and develop design criteria to minimize this problem.
4. Develop uniform mapping practices that will complement the highway information system concept. This study determined that trip planning is vital to successful performance of the driving task, and that there is a requirement for good and uniform practice in map preparations relative to driver information needs. Two areas are proposed for study. The first would be the improvement of map information display to complement the highway information system. The second, an associated study, would investigate the ability of the driver population to read maps, prepare trip plans, and investigate macro-performance-related driver expectancies. This includes the ability to: (1) understand compass directions, (2) understand weather reports and their use, and (3) translate distance into driving time.
5. Initiate a research program on the details of sign design, covering such aspects as:
a. Optimum arrangement of message.
b. Advantage of symbolic or schematic signing and, if desirable, how to use it.
c. Letter design details.

Because it is concluded that the sign will remain as the key item of the information system, it is essential that its use be optimized. Laboratory research, that is sound from the human factors point of view, is needed.
6. Initiate a research program on the possibilities of recoding information for both sign and map information presentation. This would cover such aspects as:
a. Code description of exit type.
b. Code description of highway type as to speed, clearances, stoppages, etc.
7. Initiate a human factors study to quantify human data-processing capability. Although this would require a long-term effort, the System Application Procedures rely on judgments based on this human capability.
8. Perform an analysis on aiding to serve the driver in his situational (traffic) needs. A key finding of this study is that development of new aiding techniques (such as measuring the rate of gap closure) should be emphasized to assist the driver in critical need areas. Various aiding techniques have been explored (Appendix F). A systems approach should be used to extend this work to develop an over-all program, or system concept including priorities of development, on which to base further research work.
9. Perform a systems analysis on system characteristics and techniques for accomplishing alternate routing in highway networks. This macroperformance need warrants a systems approach to lay out a sound program of development.
10. Initiate a study and experimentation program to
devise improved means for advising drivers of unusual or unexpected conditions, such as construction, closed lane.
11. Research is needed in certain areas of aiding devices (other than fixed signs) technology and application. These areas include shape coding of traffic-signal lenses, and methods of indicating approaching termination of the green interval; the optical design, optimum spacing, and other aspects of lane control signals; and technology of variable message signs for optimization of detectability and legibility.

## FIXED HIGHWAY SIGNING

## Conclusions

1. The legibility of signs under conditions of nighttime illumination is extremely sensitive to changes in sign location and to the horizontal and vertical alignment of the road.
2. Considerable differences in computed required minimum letter sizes exist for high-beam as against low-beam illumination.
3. Gross changes in relative sign position, such as those occasioned by the creation of clear recovery areas, have considerable effect on required letter sizes under all conditions of illumination.
4. The necessary changes in manuals and design procedures should be initiated so as to make letter size a design variable depending on conditions of use and location of individual signs.
5. The blockage of signs by trucks may represent a considerable problem and should be kept in mind when signs are being designed for roads with a high percentage of commercial traffic.

## Suggested Research

The following areas require further research, experimentation, empirical validation, or development:

1. Extension of the sign brightness computer simulation procedure.
a. Extension of the program to handle additional input variables such as: (1) transition curves, (2) superelevation, (3) cross slope and crown, (4) multiple-car configurations, (5) fixed sign lighting, and (6) fixed highway lighting.
b. Structuring of the program so that it outputs required letter sizes directly.
c. Structuring of the program so that it checks critical points of the approach (e.g., points of changes in alignment and midpoints of vertical curves) directly.
d. Structuring of the program so that it has the ability to check for the existence of a clear line of sight.
e. Additional field validation of program output.
f. Application of the principles used to develop a program that will handle such variables as headlight glare and sun glare.
2. Investigations of human factor variables involved in sign design.
a. Derivation of luminance-legibility relationships for
drivers with impaired vision, and for aged drivers.
b. Investigations of the perceptual factors involved in the reading of multiple sign assemblies.
c. Investigation of symbols, shapes, and numerals to detcrminc actual reading and comprehension time.
3. Investigations of the truck blockage problem.
a. Extension of the mathematical model to empirically derived distributions of truck and vehicle flow on actual highways.
b. Field validation and calibration of the model.

## REFERENCES

1. Cumming, R. W., "Progress Report of Human Factors Committee." Australian Road Research (Dec. 1962).
2. New York Times, June 19, 1967.
3. New York Times, June 17, 1967.
4. Kuprijanow, A., Rosenzweig, S., and Warskow, M. A., "Motorists' Needs and Services on Interstate Highways." NCHRP Report 64 (1969) 88 pp.
5. Smith, Wilbur, and Associates, Transportation and Parking for Tomorrow's Cities. Automobile Manufacturers Assn. (1966).
6. Highway Statistics-1968. U.S. Dept. of Trans., Bureau of Public Roads (1969).
7. Little, Arthur D., Inc., The State of the Art of Traffic Safety. Automobile Manufacturers Assn. (June 1966).
8. Baerwald, J. E., ed., Traffic Engineering Handbook. Inst. of Traffic Eng., Washington, D.C. (1965).
9. Matson, T. M., Smith, W. S., and Hurd, F. W., Traffic Engineering. McGraw-Hill (1955).
10. Accident Facts. National Safety Council, Chicago (1967).
11. Statistical Abstracts of the United States. 87th ed., U.S. Bureau of the Census (1966).
12. Woodson, W. E., and Conover, D. D., Human Engineering Guide for Equipment Design. Univ. of Calif. Press (1964).
13. Schmidt, I., and Connolly, P. L., "Visual Considerations of Man, The Vehicle and the Highway. Publ. SP 279, Soc. of Automotive Eng. (Mar. 1966).
14. Hulbert, S. F., The Application of Human Factors Research in the Design of Warning Devices for Highway-Rail Grade Crossings. Prepared for Alan M. Voorhees and Assoc., Inc., Planning and Eng. Sciences, Inc., Burbank, Calif. (1966).
15. Stevens, S. S., ed., Handbook of Experimental Psychology. Wiley (1951).
16. Cumming, R. W., "The Analysis of Skills in Driving." Australian Road Research, Vol. 9, pp. 4-14 (1964).
17. Miller, G. A., "The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for

Processing Information." Psychological Review, Vol. 63, No. 2, pp. 81-97 (1956).
18. Automotive Industries, Vol. 136, No. 6 (Mar. 15, 1967).
19. Shannon, C. E., and Weaver, W., The Mathematical Theory of Information. Univ. of Ill. Press (1954).
20. Baker, J. S., and Stebbins, W. R., Jr., Dictionary of Highway Traffic. Traffic Inst., Northwestern Univ. (1960).
21. A Policy on Geometric Design of Rural Highways. American Assn. of State Highways Officials, Washington, D.C. (1965).
22. A Policy on Design Standards-Interstate System. American Assn. of State Highways Officials, Washington, D.C.
23. Rockwell, T. H., Ernst, R., and Rulon, M. J., "Visual Requirements in Night Driving." NCHRP Report 99 (1970) 38 pp .
24. Palmer, D. R. G., "New Fog Broom to Sweep Highways Clean." American Highways, Vol. 45, No. 1, p. 688 (Apr. 1966).
25. Snow, W. B., ed., The Highway and the Landscape. Rutgers Univ. Prcss (1959).
26. Rose, R. W., "Landscaping and Roads." Traffic Eng. and Control, Vol. 9, No. 3, p. 140 (July 1967).
27. Head, J. A., "Highway Safety Elements in Aesthetic Design." Mich. Contractor and Builder, Vol. 60, No. 1 (Apr. 11, 1966).
28. Smith, B. L., and Fogo, R. D., "Some Visual Aspects of Highway Design." Hwy. Res. Record No. 172 (1967) pp. 1-20.
29. Tunnaro, C., and Pushkarev, B., Man Made America: Chaos or Control. Yale Univ. Press (1963).
30. Appleyard, D., Lynch, K., and Myer, J. R., The View From the Road. MIT Press (1964).
31. Berry, F. R., and McCabe, E. J., "Development and Use of Models in the Design of Highways." Hwy. Res. Record No. 172 (1967) pp. 21-38.
32. Weisberg, D. E., "Producing Dynamic Perspective Views by Computer Simulation." Presented at the 53rd Annual Meeting of AASHO, Salt Lake City (Oct. 1967).
33. Woods, K. B., ed., Highway Engineering Handbook. McGraw-Hill (1960).
34. U.S. Congress, 89 Th , "Highway Beautification Act of 1965." Public Law 89-285, 5.2084 (Oct. 22, 1965).
35. Wagner, L. C., and Harden, V. E., Regulation of Outdoor Advertising Along the Interstate System. Prepared for the Joint Fact-Finding Committee on Highways, Streets and Bridges of the Washington State Legislature (1962).
36. Godschalk, D. R., "Achieving Environmental Quality and the Highway Beautification Act of 1965." Hwy. Res. Record No. 182 (1967) pp. 22-24.
37. Hall, E. T., The Hidden Dimension. Doubleday (1966).
38. Sears, B. G., "Highways as Environmental Elements." Hwy. Res. Record No. 93 (1965) pp. 49-53.
39. Cherry, C., On Human Communications. 2d ed., MIT Press (1966).
40. U.S. Air Force, "Handbook of Instructions for Aerospace Personnel Subsystem Design." AFSC Manual 80-3 (1966).
41. Platt, F. N., "Operations Research on Driver Behavior." Traffic Eng., Vol. 31, No. 12, pp. 11-16 (1961).
42. Forbes, T. W., Snyder, T. E., and Pain, R. F., "Traffic Sign Requirements." Hwy. Res. Record No. 70 (1965) pp. 48-56.
43. Grime, G., "Research on Human Factors in Road Transport." Ergonomics, Vol. 1, No. 2, pp. 151-62 (1958).
44. Seale, L. M., Purpose of Task Analysis, Methods of Obtaining Task Analysis Information, Time Phasing. Conf. on the Uses of Task Analysis in the Derivation of Training and Training Equipment, Wright Air Development Center, Dayton (1959).
45. Honsberger, W. D., Michelson, S., and Gustafson, H. W., Determination of Task Analysis Content. Psychological Research Assoc., Inc., Encino, Calif. (1961).
46. Kurke, M. I., "Operational Sequence Diagrams in Systems Design." Human Factors, Vol. 3, No. 1, pp. 66-71 (1961).
47. Greenshields, B. D., "Driving Behavior and Related Problems." Hwy. Res. Record No. 25 (1963) pp. 14-31.
48. Platt, F. N., "A New Method of Measuring the Effects of Continued Driving Performance." Hwy. Res. Record No. 25 (1963) pp. 33-57.
49. Platt, F. N., "A New Method of Evaluating the Effects of Fatigue on Driver Performance." Human Factors, Vol. 6, No. 4, pp. 351-58 (1964).
50. Algea, C. W., "A Development of a Conceptual Framework for the Driving Task." Human Factors, Vol. 6, No. 4, pp. 375-82 (1964).
51. Biggs, N. L., "Directional Guidance of Motor Ve-hicles-A Preliminary Survey and Analysis." Ergonomics, Vol. 9, No. 3, pp. 193-202 (1966).
52. Miller, R. B., "A Method for Man-Machine Task Analysis." WADC-TR-53-137, Wright Air Development Center, Dayton (1953).
53. Alexander, G. J., Task Analysis to Determine Information Needs and Control Actions for Personnel in a Military Tactical Mission. Airborne Instruments Laboratory (1966) (unpublished).
54. Rashevsky, N., "Man-Machine Interaction in Automobile Driving." Traffic Safety Research Review, Vol. 9, pp. 101-7 (1965).
55. Gordon, D. A., "Experimental Isolation of the Driver's Visual Input." Human Factors, Vol. 8, No. 2, pp. 129-37 (1966).
56. Stephens, B. W., and Michaels, R. M., "Time Sharing Between Compensatory Tracking and Search-and-Recognition Tasks." Hwy. Res. Record No. 55 (1963) pp. 1-16.
57. Lefeve, B. A., "Speed Characteristics on Vertical Curves." Proc. HRB, Vol. 32 (1953) pp. 395-413.
58. Barch, A. M., "Judgments of Speed on the Open Highway." J. Appl. Psychol., Vol. 42, No. 6, pp. 362-66 (1958).
59. Denton, G. G., "A Subjective Scale of Speed When Driving a Motor Vehicle." Ergonomics, Vol. 9, No. 3, pp. 203-10 (1966).
60. Todosiev, E. P., "The Action Point Model of the Driver-Vehicle System." Experiment Station Report EES 202A-3, Ohio State Univ. (1963).
61. Wohl, J. G., "Man-Machine Steering Dynamics." Human Factors, Vol. 3, No. 4, pp. 222-28 (1961).
62. Olson, P. L., and Wachsler, R. A., "Relative Controllability of Dissimilar Cars." Human Factors, Vol. 4, No. 6, pp. 375-80 (1962).
63. Olson, P. L., "The Driver's Reference Point as a Function of Vehicle Type, Direction and Radius of Turn." Human Factors, Vol. 6, No. 4, p. 319-25 (1964).
64. Michaels, R. M., and Cozan, L. W., "Perceptual and Field Factors Causing Lateral Displacement." Hwy. Res. Record No. 25 (1963) pp. 1-13.
65. Schlesinger, L. E., and Safren, M. A., "Perceptual Analysis of the Driving Task." Hwy. Res. Record No. 84 (1963) pp. 54-61.
66. Olson, P. L., Wachsler, R. A., and Bauer, H. J., "Driver Judgments on Relative Car Velocities." J. Appl. Psychol., Vol. 45, No. 3, pp. 161-64 (1961).
67. Braunstein, M. L., and Laughery, K. R., "Detection of Vehicle Velocity Changes During Expressway Driving." Human Factors, Vol. 6, No. 4, pp. 327-31 (1964).
68. Hoppe, D. R., and Lauer, A. R., "Factors Affecting the Perception of Relative Motion and Distance Between Vehicles at Night." HRB Bull. 43 (1951) pp. 1-17.
69. Stalder, H. I., and Lauer, A. R., "Effect of Pattern Distribution on Perception of Relative Motion in Low Levels of Illumination." HRB Bull. 56 (1952) pp. 25-36.
70. Wright, S., and Sleight, R. B., "How Close is Too Close?" Traffic Safety (1961).
71. Lerner, $\dot{\text { H. D., Abbott, H. E., and Sleight, R. B., }}$ "Following Distance on the Highway Related to Speed, Trip Duration, Traffic and Illumination." Human Factors, Vol. 6, No. 4, pp. 343-50 (1964).
72. Bīerley, K. L., "Investigation of an Intervehicle Spacing Display." Hwy. Res. Record No. 25 (1963) pp. 58-75.
73. Fenton, R. E., An Improved Man-Machine Interface for the Driver-Vehicle System. Report given at the 7th IEEE Symposium on Human Factors in Electronics (May 1966).
74. Bjorkman, M., "An Exploratory Study of Predictive Judgments in a Traffic Situation." Scandinavian J. Psychol., Vol. 4, No. 2, pp. 65-76 (1962).
75. Crawford, A., "The Overtaking Driver." Ergonomics, Vol. 6, No. 2, pp. 153-70 (1963).
76. Jones, H. V., and Heimstra, N. W., "Ability of Drivers to Make Critical Passing Judgments." J. Eng. Psychol., Vol. 3, No. 4, pp. 117-22 (1964).
77. Brown, I. D., "Effect of a Car Radio on Driving in Traffic." Ergonomics, Vol. 8, No. 4, p. 475-79 (1965).
78. Hulbert, S. F., "Drivers' GSRs in Traffic." Percept. Mot. Skills, Vol. 7, pp. 305-15 (1957).
79. Taylor, D. H., "Drivers' Galvanic Skin Response and the Risk of Accident." Ergonomics, Vol. 7, No. 4, pp. 439-51 (1964).
80. Shor, R. E., "Shared Patterns of Nonverbal Normative Expectations in Automobile Driving." J. Soc. Psychol., Vol. 62 (first half), pp. 155-63 (1964).
81. Graham, C. H., "Visual Perception." Stevens, S. S., ed., Handbook of Experimental Psychology, Wiley (1951).
82. McGill, W., "Population Expectancies and Traffic System Design." Australian Road Research, Vol. 2, No. 7, pp. 19-42 (1966).
83. Senders, J. W., Kristoflevson, A. B., Levinson, W., Dietrich, C. W., and Ward, J. L., "An Investigation of Automobile Driver Information Processing." Report No. 1335, Bolt Beranek and Newman, Inc., Boston (1966).
84. Brown, I. D., and Poulton, E. C., "Measuring the Spare Mental Capacity of Car Drivers by a Subsidiary Task." Ergonomics, Vol. 4, No: 1, pp. 35-40 (1961).
85. Brown, I. D., Tickner, A. H., and Simmonds, D. C. V., "Effects of Prolonged Driving Upon Driving Skill and Performance of a Subsidiary Task." Industrial Medicine and Surgery, Vol. 35, No. 9, pp. 760-65 (1966).
86. Swets, J. A., Tanner, W. P., and Birdsull, T. G., "Decision Processes in Perception." In Swets, J. A., ed., Signal Detection and Recognition by Human Observers (1964).
87. Zuercher, J. D., "The Effects of Extraneous Stimulation in Vigilance." Human Factors, Vol. 7, No. 2, pp. 101-5 (1965).
88. Adams, J. A., "Preface to Special Human Factors Edition on Vigilance." Human Factors, Vol. 7, No. 2, p. 91 (1965).
89. Kibler, A. W., "The Relevance of Vigilance Research to Aerospace Monitoring Tasks." Human Factors, Vol. 7, No. 2, pp. 93-99 (1965).
90. Attneave, F., Applications of Information Theory to Psychology. Holt (1963).
91. Quastler, H., "Three Survey Papers." Report No. R-71, Control Systems Lab., Univ. of III. (1956).
92. Manual of Uniform Traffic Control Devices for Streets and Highways. U.S. Dept. of Commerce, Bureau of Public Roads (June 1961).
93. Manual for Signing and Pavement Marking of the National System of Interstate and Defense Highways. American Assn. of State Highway Officials (1961).
94. "Progress Toward Compliance with Manual on Uniform Traffic Control Devices." American Highways, Vol. 46, No. 2, p. 22 (Apr. 1967).
95. Manual of Uniform Traffic Control Devices for Streets and Highways. Dept. of Public Works and Buildings, Div. of Highways, State of Ill. (May 1, 1963).
96. Schoppert, D. W., Moskowitz, K. Hulbert, S. F., and Burg, A., "Some Principles of Freeway Directional Signing Based on Motorists' Experiences." HRB Bull. 244 (1960) pp. 30-87.
97. "Motorway Signs." Final Report of Advisor's Committee on Traffic Signs for Motorways, HMSO, London (1962).
98. "Draft Convention on Road Signs and Signals." Document No. E/Conf. 56/3, United Nations Economic and Social Council (Oct. 4, 1967).
99. Research on Road Traffic. Road Research Laboratory (1965).
100. Johansson, G., and Ruhr, K., "Drivers and Road Signs: A Preliminary Investigation of the Capacity of Car Drivers to Get Information From Road Signs." Ergonomics, Vol. 9, No. 1 (Jan. 1966).
101. Ferguson, W. S., and Соok, K. E., "Driver Awareness of Sign Colors and Shapes." Va. Highways Research Council (May 1967).
102. Report on Uniform Map Symbols. American Assn. of State Highway Officials (1962).
103. Usborne, T. G., "International Standardization of Road Traffic Signs." Traffic Eng., Vol. 37, No. 10, pp. 20-23 (July 1967).
104. Roalman, A. R., "Big Switch in Sweden." Traffic Safety, Vol. 67, No. 11, p. 21 (Nov. 1967).
105. Highway Statistics. Ministry of Transport, HMSO, London (1965).
106. New York Times, Oct. 4, 1967, Nov. 12, 1967.
107. Spolander, K., "One Year with Right Hand Traffic." Report No. 11, The National Swedish Road Safety Board (Sept. 1968).
108. Mackie, A. M., "A National Survey of Knowledge of the New Traffic Signs." RRL Report No. 51, Ministry of Transport, London (1966).
109. Draft Highway Safety Program Standard No. 4.4.5 -Driver Licensing. U.S. Department of Commerce, National Highway Safety Agency (Feb. 1967).
110. New York Times, Oct. 29, 1967.
111. The Chosen Million. American Automobile Assn., Washington, D.C. (1965).
112. Webb, G. M., Correlation of Geometric Design and Directional Signing. Calif. Div. of Highways (Jan. 1959).
113. IEEE Transactions on Vehicular Technology. Presentation by F. C. Turner, Vol. VT-19, No. 1 (Feb. 1970).
114. Automotive Industries, Vol. 142, No. 6 (Mar. 15, 1970).
115. Kocmond, W. C., and Perchonok, K., "Highway Fog." NCHRP Report 95 (1970) 48 pp.
116. Forbes, T. W., Pain, R. F., Fry, J. P., Jr., and Joyce, R. P., "Effect of Sign Position and Brightness on Seeing Simulated Highway Signs." Hwy. Res. Record No. 164 (1967) pp. 29-37.
117. Odescalchi, P., "Conspicuity of Signs in Rural Surroundings." Traffic Eng. and Control, p. 390 (Nov. 1960).
118. Hanson, D. R., and Woltman, H. L., "Sign Backgrounds and Angular Position." Hwy. Res. Record No. 170 (1967) pp. 82-96.
119. Forbes, T. W., Snyder, T. E., and Pain, R. F., A Study of Traffic Sign Requirements. Vol. II, "An Annotated Bibliography," Mich. State Univ. (Aug. 1965).
120. Christie. A. W., and Rutley, K. S., "Relative Effectiveness of Some Letter Types Designed for Use on Road Traffic Signs." Roads and Road Construction (Aug. 1961).
121. Kneebone, D. C., "Sign Legends." Proc. Second Conf. Australian Road Research Board, Vol. II, p. 542 (1964).
122. Case, H. W., Michael, J. L., Mount, G. E., and Brenner, R., "Analysis of Certain Variables Related to Sign Legibility." HRB Bull. 60 (1952) p. 44.
123. Kelly, K. L., "Twenty-Two Colors of Maximum Contrast." Color Eng., Vol. 3, No. 6 (Nov. 1965) p. 26.
124. Brainerd, R. W., Cambell, R. S., and Elkin, E. H., "Design and Interpretability of Road Signs." J. A ppl. Psychol., Vol. 15, No. 2, pp. 130-36 (1961).
125. Woltman, H. L., "A Study of Dew and Frost Formation on Retro-Reflectors." Hwy. Res. Record No. 7 (1965) pp. 63-66.
126. Gregsten, M. J., "Advance Direction Signs and Specular Reflection." Traffic Eng. and Control, pp. 347-49 (Oct. 1961).
127. Pritchard, B. S., and Blackwell, H. R., "Optical Properties of the Atmosphere and Highway Lighting in Fog." HRB Bull. 191 (1958) pp. 7-16.
128. Haber, H., "Safety Hazard of Tinted Automobile Windshields at Night." HRB Bull. 127 (1956) pp. 45-52.
129. Richards, O. W., "Tinted Contact Lenses-A Handicap for Night Driving." Hwy. Res. Record No. 25 (1963) p. 86.
130. Mitchell, A., and Forbes, T. W., "Design of Sign

Letter Sizes." Proc. Amer. Soc. Civil Eng., Vol. 68, No. 1, p. 104 (1942).
131. Moore, R. L., and Christie, A. W., "Direction Signs for Motorways." The Engineer (May 13, 1960).
132. Odescalchi, P., Rutley, K. S., and Christie, A. E., "The Time Taken to Read a Traffic Sign and its Effect on the Size of Lettering Necessary." Note No. LN/98/90 KSR AWC, Road Research Laboratory (1962).
133. Allen, T. M., Dyer, F. M., Smith, G. M., and Janson, M. H., "Luminance Requirements for Illuminated Signs." Hwy. Res. Record No. 179 (1967) pp. 16-37.
134. Straub, A. L., and Allen, T. M., "Sign Brightness in Relation to Position, Distance and Reflectorization." HRB Bull. 146 (1956) pp. 13-44.
135. Van Lear, G. A., Jr., "Reflectors used in Highway Sign and Warning Signals." J. Optical Soc. of America, Vol. 30, No. 10 (Oct. 1940).
136. Finch, D. M., "Reflex Reflector Performance Criteria." HRB Bull. 34 (1951) pp. 21-40.
137. Chandler, K. N., and Reid, J. A., "Reflex Reflectors." Tech. Paper No. 42, Dept. of Scientific and Industrial Research, Road Research Laboratory (1958).
138. Giovanelli, R. G., "Retroreflectors for Use on Road Signs and Vehicles." National Standards Lab. Tech. Paper No. 5, Commonwealth Scientific and Industrial Research Org., Melbourne, Australia (1954).
139. Meyer, C. F., Route Surveying. International Textbook Company, Scranton, Pa. (1949).
140. "Lighting Equipment and Photometric Tests." Handbook Supp. No. 34, Soc. of Automotive Eng., N.Y. (1967).
141. Hare, C. T., and Hemion, R. H., Headlight Beam Usage on U.S. Highways. Southwest Research Inst., San Antonio (Dec. 1968).
142. Lee, C. L., "Driver Eye Height and Related Highway Design Features." Proc. HRB, Vol. 39 (1960) pp. 46-60.
143. Stonex, K. A., "Driver Eye Height and Vehicle Performance in Relation to Crest Sight Distance and Length of No-Passing Zones." HRB Bull. 195 (1958) pp. 1-4.
144. Stonex, K. A., "Trends of Vehicle Dimensions and Performance Characteristics." Paper No. 539 A, Soc. of Automotive Eng., N.Y. (1962).
145. Meldrum, J. F., "Automobile Driver Eye Position." Paper No. 650464, Soc. of Automotive Eng., N.Y. (1965).
146. Baerwald, J. D., ed., Traffic Engineering Handbook. 2d ed., Inst. of Traffic Eng., Washington, D.C. (1965).
147. Stiles, Bennet, and Green, "Visibility of Light Signals with Special Reference to Aviation Light." Reports and Memoranda, No. 1793, British Air Ministry, Aeronautical Research Comm., London (May 1937).
148. Lash, J. D., and Prideaux, G. F. F., "Visibility of Signal Lights." Illumination Eng., Vol. 38, No. 9 (Nov. 1943).
149. Projector, T. H., and Robinson, J. E., Jr., "Midair Collision Avoidance with Navigation Light Systems." Airway Modernization Board (AMB), Applied Psychology Corp. (Sept. 1958).
150. Nock, T. N., Dunlop, D. R., and Finch, D. M., Voltages in Motor Vehicle Lighting Circuits. Prepared for the Calif. Highway Patrol by the Univ. of Calif., Berkeley (Jan. 1966).
151. "Characteristics Indication for Large and Miniature Filament Lamps." TPC-25, General Electric Co.
152. Croxton, F. E., and Cowden, D. J., Applied General Statistics. 2d ed., Prentice-Hall (1956).
153. Standard Alphabets for Highway Signs. U.S. Dept. of Commerce, Bureau of Public Roads (1966).
154. Cheeseman, M. R., and Voss, W. T., "Motor Vehicle Headlight Beam Usage on a Section of

Interstate Highway 90." Hwy. Res. Record No. 164 (1967) pp. 17-20.
155. Forbes, T. W., Pain, R. F., Joyce, R. P., and Fry, J. P., Jr., "Color and Brightness Factors in Simulated and Full-Scale Traffic Sign Visibility." Hwy. Res. Record No. 216 (1968) pp. 55-65.
156. Cox, N. T., "The Effect of Dirt on Vehicle Headlamp Performance." Report LR 240, Road Research Laboratory (1968).
157. Sign Specification Supplement. N.C. State Highway Comm. (Jan. 1969).
158. Heller, F., "Rules for the Dimensioning and Arrangement of Verbal Message Traffic Signs." Strassenverkehrstechnik, Vol. 1, No. 12 (Dec. 1957) (in German).
159. Highway Design and Operational Practices Related to Highway Safety. Special AASHO Traffic Safety Committee, Washington, D.C. (1967).
160. A Study of Lateral Sign Placement. Conn. Highway Dept., Bureau of Traffic (June 1969).

## APPENDIX A

## DETAILS OF TASK ANALYSIS AND OTHER ANALYTIC PROCEDURES *

## DEVELOPMENT OF ANALYTIC TECHNIQUE

To find out exactly what information drivers need, it was necessary to determine exactly what the driver does. The analytic method starts from the foundation of a description of the driving task. The first question was: "What task analytic technique would yield the most meaningful results in terms of describing the task?" To answer this question, two tasks were undertaken: (1) the literature was searched for tutorial papers on types and uses of task analysis, and (2) a preliminary field trip was made to determine the best technique for collecting data.

Two other questions were to be considered: (1) Because the information needs derived must fit into the "future" highway system, what will the future system be like? and (2) How does the body of human factors research in the highway field affect the effort to be undertaken? The first question resulted in several trips by the researchers to various areas of the U.S. to find out how the system will be different in 10 to 15 years. An extension of the literature survey was planned to answer the second question.

The Work Plan called for two of the researchers to collect data, one to drive and the other to record observations. From several short drives in the Long Island, N.Y., area, it became apparent that passenger-recorded observa-

[^31]tions would be inadequate. To make subsequent analysis of task data possible, it would be necessary to record not only what the driver was doing, but also what elements attract his attention and at what point in the trip events were occurring. It was decided, therefore, that the driver was the only one capable of recording the most relevant data.

It was also decided that one long trip (several hundred miles) should be used as the baseline of the task analysis and that the data factors to be recorded should be as given in Table A-1.

## ORIGINAL TASK ANALYSIS FORMAT

Task analysis may be defined as that portion of the total systems analysis effort that defines systematically, and in as much detail as possible at any given time, the stimulus inputs to the operator, the response outputs of the operator, and the operational environment in which he works.

## Determination of Approach

To evaluate alternative methods of analysis, and select the method and format most appropriate, each of the possible methods was tested using data collected on the preliminary field trips to determine what would be the data outputs. The output required was that which yielded the most

TABLE A-1

## DATA FACTORS REPORTED ON TRIP TO LANSING, MICHIGAN

| Driving elements: | Driving conditions elements: <br> Starting <br> Stopping |
| :--- | :--- |
| Turning | Weather |
| Backing | Roadway |
| Decreasing gap (front) | Auto factors |
| Decreasing gap (rear) | Visibility |
| Increasing gap (front) | Dangerous conditions |
| Increasing gap (rear) | Expectations |
| Accelerating | Incidental activity: |
| Decelerating | Turn on lights |
| Lane changing | Turn on wipers |
| Passing | Turn directional signals |
| Monitoring elements: |  |
| Relative position |  |
| Sign readings |  |
| Mirror readings |  |
| Road obstructions |  |
| Auto status (speed, fuel, etc.) |  |

information about the driver, the vehicle, and the environment in the dynamic situation.

It was decided that the best method of analysis would allow the analyst to use empirical data as a basis for the work to follow. An actual trip, long enough to permit driving under a variety of conditions, was planned. Before the data to be used were collected, a gross structure of the analysis format was developed. The structure was based on one developed by one of the researchers in connection with a study to determine information needs and control actions required of pilots and other personnel in a military tactical mission. This format has been used successfully in several military projects that required a comprehensive description of operator tasks. Two project personnel then planned a two-day trip from New York City to Lansing, Mich. A car was rented for the trip and the entire trip was recorded by the driver using a portable tape recorder. After the tape was analyzed, certain refinements were made in the format structure. The final structure is given in Table A-2.

When the data were analyzed, it was found that driver expectation was an important factor in determining needs pertaining to directional information. Rather than change the structure of the entire analysis format, a second structure was made to cover this kind of need (Table A-3).

The most important difference between the two structures is the inclusion of expectancy in the latter. This allows a comparison between what the driver thinks the information presented to him will be and the actual information presented. The data inserted into this structure were gathered in the same way as the previous task description, but were taken from a trip from Seattle-Tacoma airport to downtown Seattle via I-5.

## Constraints

## Recording Technique

A problem associated with the data-collecting phase of the task analysis implementation was in the method used for collecting the data. Although the procedure yielded a great amount of meaningful data, and represented the best procedure available within the limitations of the project, it had several limitations.

The recording technique was limited in the amount of information relating to road topography, signing, traffic dynamics, etc., that could be included. Because the driver was required to drive as well as record and therefore spent a large amount of time attending to the driving task, he had to limit his recording to high points rather than to a continuous running record.

Another drawback is that the person doing the recording is required to structure his verbal report in a specific way so as to render it amenable to analysis. For example, three individuals took part in the recording activity, but only one was able to structure his report in a usable form.

## Situations Encountered

A problem associated with the data-collecting phase of the task analysis was the lack of an exhaustive inventory of situations. Although a 700 -mile trip was recorded, there was no way to experience the many situations that confront a driver. For example, the entire trip was taken in fair weather. Empirical data, therefore, were not available on - possible other needs that arise because of rain, sleet, fog, snow, hail, and many other variables. To obtain some idea of the number of situations that could be encountered by a driver, Table A-4 was constructed. It gives some of the more salient variables that could affect driving performance at any given time.

## Simulated Data

To determine how serious this last constraint is, it was necessary to determine whether information needs change as a result of changes in environment or road type or ambient lighting.

To answer this question, it was necessary to superimpose some of the variables mentioned over an actual driving sequence (baseline data) and determine the effect. An important factor determined by the baseline segment of the driving task analysis is that the drivers manifested consistent and predictable driving behavior within a particular situation. Although the data obtained by the driving task analysis are not amenable to quantitative statistical manipulation, it appears that, if such were the case, the data would yield a high reliability coefficient both in terms of internal consistency and predictability.

Driving behavior varies from driver to driver and from situation to situation; that is, drivers A and B may manifest different driving behavior on the same road under the same environmental conditions. It is also possible for driver A or driver B to exhibit different driving behavior from road to road and from one environmental condition to another. However, within a particular situation, the driving behavior of a particular driver appears to be reliable.

TABLE A-2
TASK ANALYSIS-VEHICLE CONTROL

| Item |  | $\begin{aligned} & \text { Speed } \\ & \text { (mph) } \end{aligned}$ | Road Conditions and Traffic Dynamics | Driver Dynamics |  |  | VehicleResponse | FeedBack | Distractions | Remarks |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| No. | $\begin{array}{\|l\|} \hline \text { Elapsed } \\ \text { Milage } \end{array}$ |  |  | Perception | Cognition | Response |  |  |  | $\begin{gathered} \text { Suggested } \\ \text { Information Aids } \end{gathered}$ | Comments |
| 1 | - | - | - |  | - | - | - | - | - | - | - |
| 1A | 000.0 | 00 | Parking lot | Rented car | Ev ${ }^{1}$ New car <br> PR $^{2}$ All equipment operative <br> DEC. ${ }^{3}$ Since car rented must familiarize self with equipment | - Enter car <br> - Adjust seat <br> - Adjust seat belt <br> - Adjust mirror <br> - Determine location of equipment | None | V/T | - | Gauges and displays In car to show all systems operative | Predriving task |
|  |  |  |  | All equipment adjusted | EV. All equipment adjusted <br> PR. Will perform satisfactorily <br> DEC. Start car | - Place key in Ignition <br> - turn key | Car starts | V/T/A | - | See above | 1st driver task under all situations. <br> - Time: Morning <br> - Weather: Clear <br> - Driver: Alert |
| 1B | 000.0 | 20 | Road: Single access lane feeding into "main" road <br> Traffic: Access lane clear of traffic | Clear access lane leading into desired road | EV. Access lane clear <br> PR. Will lead to desired road <br> DEC. Turn on to access lane | - Put car into gear <br> - Turn wheel to desired direction <br> - Depress gas pedal lightly | Car moves onto access lane at 20 mph | V/T/K | Pedestrians | Directional information showing where access leads to |  |
|  | 000.3 | 10 | Road: Juncture of access lane and "main" roàd <br> Traffic: Access lane clear of traffic | Yield Sign. | EV. Other cars have right of way. <br> PR. Will encounter traffic of "main" road but merge is such that entrance onto main road can be accomplished without full stop. full stop. | Take foot off gas pedal and let car coast to merge point | Car slows | V/T/K | . | Description of traffic conditions ahead Directional information showing where "maln" road leads Number and name of main road | Anticipatory task requiring vigilance on driver's part <br> Could be danger point under poor ambient conditions |
| ${ }^{1}$ Evaluation <br> ${ }^{2}$ Prediction |  | ${ }^{3}$ Decision |  |  |  |  |  |  |  |  |  |

TABLE A-3
TASK ANALYSIS—DIRECTION FINDING

| Trip |  | Mapping |  | Expectancies | Driver |  |  | Remarks |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| MileStone | Milage | Travel Segment | Map Detalls |  | Perception | Cognition | Response | Information Aids | Comments |
| I | - | Mapping phase - prior to actual trip. | Gas company (Standared Oil Co. of California) Map - 1967 Ed. of Seattle. | Starting from hotel, expectatation is to take Route 99 Northbound to Route 518, Eastbound on Route 518 to Route 5 (Freeway), Northbound on Route 5 to Lakeview Roanoke Street exit, Lakeview Boulevard Northbound making left under Freeway to Boylston St., right on Boylston St., Boylston St. Northbound to Roanoke St., right onto Roanqke St., Roanoke St. Eastbound to destination. |  |  |  |  |  |
| I-1 | 00.0 | On Pacific Highway (Route 99) Northbound. | Pacific Highway shown as "main road" (solid red) running $\mathrm{N}-\mathrm{S}$ and parallel to Freeway. NDT called Route 99 on map. | Expect To Take Route 99 to Route 518. | Route 99 is four tane undivided highway with <br> 45 mille limit. | EV. On Route 99 Northbound <br> PR. Will lead to Route 518 DEC. Proceed on course | Proceed on road. | Route names and signs. Distance to 518 . | Start of recording for task analysis. <br> S expresses that he is on 99 even though no slgns exlst saying Route 99. |

The baseline segment of the driving task analysis established driving behavior for two drivers under essentially "optimum" road and weather conditions. In view of the reliable nature of the driving behavior as determined by the driving task analysis, it was assumed that predicting a

TABLE A-4
VARIABLES IN DRIVING SITUATIONS

| Ambient lighting: |
| :--- |
| Daylight |
| Dawn and dusk |
| Night (highway lighted) |
| Night (highway unlighted) |
| Glare and haze |
| Environmental conditions: |
| Clear weather |
| Rain |
| Snow |
| Fog |
| Sleet and hail |
| Road types: |
| Interstate with medial strip |
| Interstate with medial barrier |
| Four lane no medial |
| Four lane no medial, no lane markers |
| Three lane with lane markers |
| Three lane without lane markers |
| Two lane |
| Road environment: |
| Bridge |
| No shoulder |
| Viaduct |
| Tunnel |
| Road geometrics: |
| Straight and level |
| Straight upgrade |
| Straight downgrade |
| Curve level |
| Curve upgrade |
| Curve downgrade |
| Road construction: |
| Concrete |
| Asphalt |
| Bridge grating |
| Other |
| Road surface: |
| Dry |
| Wet |
| Snow and ice covered |
| Sand covered |
| Traffic density: |
| Light |
| Medium |
| Heavy |
| Speed (mph): |
| Stopped |
| 10 to 35 |
| 35 to 50 |
| 50 to 70 |
| Over 70 |

Daylight
Dawn and dusk
Night (highway lighted)
Night (highway unlighted)
Glare and haze
Environmental conditions:
Clear weather
Rain
Snow
Sleet and hail
Road types:
Interstate with medial strip barrier Four lane no medial Three lane with lane markers Three lane without lane markers Two lane
oad environment:
Bridge
Viaduct
Tunnel
Road geometrics:
Straight and level
Straight upgrade
Curve level
Curve upgrade
Curve downgrade
Concrete
Asphalt
Bridge grating
Other
Road surface:
Dry
Snow and ice covered
Sand covered
Traffic density:
Ligh
Medium
Speed (mph):
Stopped
10 to 35
50 to 70
Over 70
particular driver's driving behavior under conditions that differ from those encountered in the baseline segments would be valid. This assumption is based on the fact that different environmental and road conditions seem to modify existing patterns rather than to initiate new driving behavior. Therefore, because road and environmental conditions can be specified and because the driver's driving patterns are known, it will be possible to superimpose the changed conditions over the known driving behavior and arrive at the predicted modified driving behavior.

Each of the simulation sequences covered approximately 3 miles of travel. The sequence reproduced, as closely as possible, an identical sequence taken from the completed portion of the baseline of the driving task analysis with the exception of the variables to be simulated. This allowed a comparison of the actual baseline and the simulated sequence. It is also noted that certain changes in content arose due to the nature of the simulated situation; for example, with a wet road and a sleepy driver, a situation may occur where the driver runs off the road, whereas such was not the case in the actual baseline segment.

## DEVELOPMENT OF MODELS

To facilitate analysis of the data obtained from the driving task analyses, it was determined that the construction of a model of the driving task would yield a useful and simple allalug of information inputs to the driver vehicle environment system. This model, when developed, provided the theoretical basis for structuring the information needs of the operator in terms of several discrete information input categories.

In servomechanical terms, the driving task model represents a closed loop system, with information about the interaction of the driver-vehicle-environment fed back and compared to the input to yield an error signal. The driving task is then considered as a series of operations designed to reduce this error signal to zero.

## Driver Transfer Function

Before the driving task model is considered, it is necessary to introduce the concept of a driver transfer function because of its prominence in the driving task model. The transfer function is a way of analyzing the behavior of each component in a system (driver, vehicle) in terms of its inputs and outputs. The driver transfer function describes the way in which the human operator (component) processes (transfers) his information (inputs) and transforms it into vehicle control movements (outputs).

It is known that the human operator introduces errors into any system. Factors such as reaction time, fatigue, and learning contribute to these errors. The way in which these factors operate is complex and varies from time to time and from person to person. The fact that the human component is so complex and variable makes it impossible to describe the driver transfer function except in general terms. For this study, it is assumed that the driver transfer function represents the operator-vehicle interaction, generalizable to any situation that can be shown schematically.

In Figure A-1, $R_{(S)}$ is the 'system input or reference


Figure A-1. Driver transfer function.
variable. In driving terms, $R_{(S)}$ can be lane maintenance, avoidance of obstacles, or going from point $A$ to point $B$. The diagram shown in Figure A-1 is generalized in terms of going from one point to another. In this case, between point $A$ (start) and point $B$ (destination), the system is never in equilibrium and an error variable, $E_{(S)}$ exists. This error signal is reduced to zero (mission requirement) at point B. The driver output, $C H_{(S)}$, corresponds to the control operations the driver makes to reduce the error signal to zero (arrival at destination). The system output, $C_{(S)}$, is the output of the vehicle in going from point A to point B-that is, vehicle position.

The diagram also shows the derivatives of the vehicle output, with respect to time. $\dot{C}_{(S)}$ is the first derivative of distance, which is speed. $\ddot{C}_{(S)}$ is the second derivative of distance, which is acceleration.

Figure A-1 shows that the operator is continuously receiving feedback from the vehicle. It is noted that a parallel feedback from $\dot{C}_{(S)}$ (velocity) is additive to the feedback loop. This is because the vehicle displays velocity directly by means of the speedometer. It is also noted that $C_{(S)}$, or distance traversed, is also directly displayed by means of the odometer.

## Driving Task Model

The Driver Transfer Function provides a description of the interface between the operator and the vehicle. From this description, it is seen that the vehicle provides the operator with information about the vehicle's outputs via a direct feedback loop.

However, because most information relating to speed, location, direction, etc., is obtained from the environment, it is necessary to construct a model that takes into account both the Driver Transfer Function and events in the environment.

The model shown in Figure A-2 satisfies this require-
ment. The value of the model for this project is that it presents an analog of the driving task as a driver-vehicleenvironment system and identifies external inputs to the system in a sequential order.

Sequentially, the first environmental input to the drivervehicle system is the interaction of the vehicle and the road. This input is called Road Information and takes into account information such as road surface, and road alignment. The feedback loop described is identified in Figure A-2 as "vehicle feedback loop." As is shown in Figure A-2, a parallel feedback loop external to the vehicle, identified as the "main feedback loop," exists that inputs to the driver and is compared with the system input to form the error signal.

Figure A-2 also shows that Road Information interacts with the output from the transfer function to generate an item of transfer identified as Road Directional in the model. Road Directional refers to that modification of the error signal caused by the Road Information inputs. Examples of Road Directional are going forward in lane, and responding to road alignment.

Sequentially, the next category of information that has input into the model is identified as Traffic Information. Information about traffic adds to the other information through the "main feedback loop" to affect the error signal.

The model shows that Traffic Information generates another item of transfer containing the Road Directional loop that is called Traffic Directional. Traffic Directional refers to the modifications to the error signal caused by lane changes to avoid traffic, slow down in response to traffic, etc.

The next category of environmental information inputting to the model is a category called Advisory, Restrictive, Inhibitive Information. This category takes into account such information as regulations, detours, and cautions. This information adds to the other information through the main feedback loop and interacts with the Road Direc-


Figure A-2. Driving task model.
tional and Traffic Directional loops to affect the error signal.

A final category of informational input to the model is called Directional Information and takes into account route signs, interchanges, direction signs, etc. This information input adds directly into the "main feedback loop."

## EXTENDED TASK ANALYSIS FORMAT

Later in the project, when identification of drivers' information needs on a specific stretch of highway was required, it became necessary to modify the original task analysis format in order to overcome some of the constraints listed previously herein. The revised task analysis included data collection by the use of a filmed record synchronized with the verbal recording technique of the original format.

By employing this method, objective data (by means of the film) and a subjective evaluation (by means of the verbal introspections of the driver) could be obtained. This permitted a comparison of what actually occurred with what the driver perceived.

In addition, the filmed record of the site enabled project personnel to "bring the test site into the laboratory" and thus provided an immediate means of verifying data obtained from other sources such as signing and construction plans.

## Equipment Requirements and Development of Techniques

A determination of data-taking equipment requirements and the development of data collection techniques was made. Because the method involved both a filming and a verbal recording technique, equipment requirements and data collection methods for both aspects were determined.

No change in voice recording technique from the original task analysis was required. That is, the driver (i.e., observer) recorded his verbal observations while driving.

Therefore, the main emphasis was placed on the development of equipment requirements and data collection techniques for the filming portion of the data collection task.

## Equipment Requirements

The data collection method required that a continuous visual record be made of the test site so as to represent, as closely and accurately as possible, the field of view of the driver. This necessitated the use of professional, portable filming equipment capable of taking continuous, wide-angle, high-quality color film.

The equipment used to film the test site consisted of:

1. Camera-Arriflex 16: a $16-\mathrm{mm}$ camera with variable speed control to allow filming at speeds from 5 to 50 frames per second.
2. Lens-13-mm lens: a wide-angle lens that provides $100^{\circ}$ of field from 10 ft to infinity.
3. Magazine-400-ft-capacity magazine: an extended magazine to provide for continuous filming of the site without changing film magazines.
4. Ancillary equipment-a battery power pack: so the camera would not have to be hand wound; a stabilizer and shoulder harness enable the camera man to hold the camera steady; and a neutral density filter.
5. Film-Ektachrome Type 7241: reversal color film.

## Filming Techniques

The basic filming technique factors resolved were film speed and camera position.

1. Film speed-The film was taken at a speed of 8 frames per second. With this speed, and a magazine of 400 -ft capacity, approximately 28 min of continuous filming could be achieved. Because the time to drive through the North Carolina site at the posted speed limit ( 60 to 65 mph ) was approximately 21 min , a film speed of 8 frames per second yielded the necessary continuity. However, it must be pointed out that the 8 -frames-per-second speed represented a tradeoff between film resolution and continuity. As a result of this tradeoff, resolution of the completed film was somewhat below par, leading to some difficulty (e.g., reading legends on small signs) during analysis.
2. Camera placement-A "view from the road," similar to that of the driver's, was required. Several different
camera placements were attempted, including shooting the film over the shoulder of the driver, and filming from above the driver's head in an open convertible. With an "over-the-shoulder" placement, distortion was produced, whereas an "over-the-head" placement provided an unrealistic "truck-cabin" view of the road.

The filming position ultimately selected consisted of placing the camera on the front seat of the vehicle, as close to the driver as possible, and filming through the windshield of the car. It proved impossible to obtain a non-air-conditioned car. However, the color distortion introduced by the tinted windshield proved to be negligible.

## Field Data Collection

Once the filming techniques and equipment requirements were refined, collection of data in the field was accomplished at the site (I-85 and US 70 in the Durham, N.C., area).

Two data collection runs, using an open convertible, were made in each direction on both I-85 and US 70. Filming was accomplished as close to midday as possible to negate the effects of sun position, with the weather clear and sunny during all test runs. The driver recorded his observations into a tape recorder as he drove, while a cameraman filmed the road from the front seat. An observer monitored the equipment throughout the run and made independent observations.

Throughout the runs, the speed of the vehicle was maintained as close to the posted speed limit ( 65 and 60 mph for I-85; variable for US 70) as possible. The verbal recording was synchronized to the film by recording, constantly and continuously, speedometer and odometer readings and by keying these readings to readily recognizable and unique landmarks. Landmarks included specific signs, entrances, exits, and features off the traveled way. This method enabled reasonably good synchronization of film and tape and also provided a means of localizing events during the analysis phase discussed subsequently.

Because the filming was accomplished during good weather conditions, in daylight hours during the summer, the site was revisited during the fall to obtain data relative to seasonal changes. During this second visit to the test site, data were also collected under night and fog conditions. Because the environmental conditions and ambient lighting precluded the use of the filming technique, data collection was by verbal means only.

## Data Reduction Methods

## Data Reduction Requirements

To analyze the data collected in the field, it was necessary to formulate data reduction methods that would permit the following:

1. An analysis of the over-all task of negotiating the site. To achieve this goal, the data had to be displayed so as to reproduce field conditions, both temporally and spatially.
2. An analysis of the site that would enable the task of driving through the site to be differentiated into its component subtasks in accordance with the hierarchial
conceptualization of the driving task. To achieve this goal, the data had to be displayed on a subtask-by-subtask basis (i.e., on an information-decision-action = subtask basis).
3. An analysis of the site that would be amenable to a location-by-location data reduction so that all information available could be determined. To achieve this goal, the data had to be displayed on a stop-frame basis.

Thus, the data reduction requirements pointed to the need for equipment capable of providing continuous as well as "stop action" display.

## Data Reduction Equipment

The data obtained in the field were reduced by synchronizing the audio record (tape) with the visual record (film) using a Concord tape recorder and a Vanguard Motion Analyzer (Fig. A-3).

The Vanguard Motion Analyzer consists of a projection head and frame register (Fig. A-4), an $81 / 2$ - by $11-\mathrm{in}$. viewing screen, and a control box (Fig. A-5). The device enables the film taken on the site to be projected on the viewing screen continuously at "road" speed, one frame at a time, or forward and backward at variable speeds from less than one frame per second to greater than 24 frames per second. The frame register provided an accurate cumulative frame count so that each frame could be numbered consecutively. (By experimentation, the device was found to have a cumulative error of 27 frames in 13,750 , corresponding to a total error of less than 0.2 percent.)

## Data Reduction Techniques

Implicit in the analysis is the concept that subtasks are initiated in two ways: (1) externally generated by the system, and (2) internally generated by the driver. Externally generated subtasks are initiated in response to occurrences on the road such as geometric features, interchanges, and traffic. Internally generated subtasks are initiated by the driver as a result of needs, such as need for service or need for directional information. An information need (internal) or an information reception (external) initiates behavioral sequences corresponding to subtasks of the over-all driving task.

The human factors analysis performed for this project is based on the concept of sequences initiated by information needs and/or presentations and is called a sequential analysis.

To perform this analysis, it was necessary to reduce the data collected in the field so as to identify and quantify these sequences.

When the data were analyzed, the film displayed on the Vanguard analyzer was synchronized with the sound recording, the film was scanned, and beginnings and ends of sequences were noted.

In the analysis of the film and the tape to determine sequences, a steady-state condition was used as a point of departure. In the steady-state condition the road is essentially straight and level with no alignment changes, grade changes, exits, entrances, cross-sectional changes, etc. In


Figure A-3. Data reduction set-up.
this condition, the only control actions that the driver is performing are straight-line tracking and speed control.

Initially, a sequence was determined as any change from the steady state, either behavioral or cognitive, where an information need or information presentation initiated the need for a decision that may or may not result in a control action or actions. Subsequently, a sequence was determined to be any subtask due to an information need or information presentation.
As a sequence was determined from the film and tape, it was given an identifying number and a start and finish point, which was read from the Vanguard's frame register. This frame count enabled the sequences, and any event or information display occurring within the sequence, to be localized in both time and space.
Time was determined by dividing the register reading by 8 , because the film was taken at a speed of 8 frames per second. Distance was obtained by multiplying the time
reading by the vehicle's speed (obtained from the tape record).

For example, an event such as a road sign occurring at register reading 64 occurred 8 sec after the start of the film. If the vehicle is known to be traveling at a speed of 60 mph ( 88 fps ), the event can be positioned at about 700 ft from the start of the filming.

The exact location was accurately positioned by fixing it to a known landmark read from the construction and/or signing plans of the road. This procedure was followed throughout the analysis phase to obtain time and distance relationships.

## Data Analysis Techniques

Three analyses were performed: (1) an over-all analysis, (2) a within-sequence analysis, and (3) a between-sequence analysis. The over-all analysis served to determine the occurrence of the various subtasks. The within-sequence
analysis provided data relative to the way in which each subtask of the over-all driving task was performed. The between-sequence analysis provided data relative to the interaction of these subtasks.

## Over-All Analysis

The over-all analysis technique entailed a scanning of the film and tape record to determine the occurrence of sequences. Using the film and tape in conjunction with the existing signing and construction plans, a detailed analysis was made as to the occurrence of sequences-primarily situational and macroperformance. A preliminary analysis indicated that certain subtasks of the driving task could not be fully analyzed, owing to the variability of their occurrence. That is, the microperformance of vehicle control as it is related to vehicle operating and handling characteristics was too much predicated on individual vehicle characteristics and driver habits to be amenable to the type of analysis being performed. Similarly, it was deemed that traffic-situational aspects of the driving task could not be analyzed. This was due to the lack of predictability and representativeness of the traffic situational events that occurred in the course of the data collecting phases.

Therefore, the over-all analysis was directed toward fixed aspects of the highway and environment, with traffic situational subtasks and information needs considered insofar as they could be predicted and information about their occurrence provided on a fixed formal information carrier basis. For example, it could be predicted that there would be an interaction of traffic at ramps, the occurrence of which could be inferentially indicated to the driver by the display of a MERGING TRAFFIC sign.

The technique that was used to perform the over-all analysis was to start with the plans and film at the beginning of the run and to block out the plans in terms of over-all trip objectives. Thus, initially, the plans and film were considered from a macroperformance standpointthat is, as if each interchange were the one that the driver might be taking. This procedure yielded a main-line and an off-line determination of the roadway, the main line being the over-all length of the road, and the off line being each interchange.

The inception of the data rollection for the site was on the main line of the road. Each off line (i.e., exit and entrance) was determined and noted, as if the exit were to be taken, and as if the entrance were one on which the driver were entering the main line.

Following this procedure, the main line was re-examined for subtask occurrence-that is, the film and voice record were scanned, and the occurrence of subtasks was noted. In implementing this analysis, a start of sequence, based on information reception or need, was noted and its occurrence in terms of the film register readings was recorded. After the main line was scanned, the path off the traveled way was similarly scanned. In this manner, the whole section of the site was partitioned and a universe of subtasks was obtained. The format used for this analysis is shown in Figure A-8.


Figure A-4. Motion analyzer-projection head and frame register.

## Within-Sequence Analysis

The first part of the within-sequence analysis was concerned with specification of each sequence in terms of the perceptual, cognitive, and action phases of the behavioral subtask it represented. Several examples have been prepared to show how the sequences were conceptualized.


Figure A-5. Motion analyzer-control box.


Figure A-6. Generalized horizontal alignment change sequence.

Figure A-6 shows a description of a generalized horizontal alignment change. The figure shows that the sequence is subdivided into a perceptual phase and an action phase. All relationships are shown in terms of time, obtained from the register reading. $t_{\mathrm{ss}-\mathrm{hac}}$ (time from steady state to start of horizontal alignment change) represents the steady-state condition prior to the start of the alignment change, when the road is straight and level.
$t_{\text {phac }}$ (time to perceive horizontal alignment change) represents the time interval from the first perception of the impending alignment change to the start of the actual alignment change. This is the "information-decision" portion of the sequence where the information that an alignment change is about to occur is received and the decision to track the curve is made (this decision is not necessarily made on the conscious level).


Figure A-7. Right-hand off-ramp exit sequence.
$t_{\text {hac }}$ (time of the horizontal alignment change) represents the time interval from the start of the horizontal curve to the end of the horizontal curve. It is during this time that the control actions necessary to track the curve are initiated and maintained throughout the alignment change. This is the "action" portion of the sequence.

In Figure A-7 a more complicated sequence, a standard exit with a right-hand off-ramp, is shown schematically. This sequence is diagrammed to illustrate the complexity that a sequence can take, and also to show how considerable time and distance can be involved within any given sequence.
$t_{\mathrm{pra}}$ (time to perceive and read advance guide sign) represents the time span from the first perception of an advance guide sign to the time when the sign becomes fully readable to the driver. The significance of $t_{\text {pra }}$ (also $t_{\text {pre }}$ ) stems from the fact that considerable information can be obtained from a sign prior to its message becoming legible. For example, the shape and color of the sign indicate what type of sign it is and what purpose it serves. This enables a driver to either pay attention to the sign or ignore it. In a high-signal area where the driver has to pay attention to many sources of information, the time period represented by $t_{\text {pra }}$ (and $t_{\text {pre }}$ ) can be very important in terms of the driver's load-shedding behavior.
$t_{\text {rsa }}$ (time to read the advance guide sign) represents the time period from when the sign becomes legible until it passes out of view (i.e., the time that the driver has in which to read the sign). The time when the advance warning sign becomes readable initiates the sequence for the exit, represented by $t_{\mathrm{ac}}$ (time of action for the exit), which terminates at the last action to take the exit.

If the specific exit is not one that the driver will take, the sequence in effect is complete and does not have an action component.

However, when sequences of this nature were being analyzed it was assumed that the driver would take the exit, and the sequence was analyzed on this basis.

Because the advance guide sign could be 2 miles, 1 mile, or $1 / 2$ mile in advance of the exit, it can be seen that $t_{\mathrm{ae}}$ can span a considerable distance, and the span can be discontinuous until the exit direction sign is reached or until the exit is perceived unaided.
$t_{\mathrm{pe}}$ (time to perceive the exit) represents the time period from the first perception of the actual exit to the start of the deceleration lane. If the advance guide sign is missed or is nonexistent, the actual perception of an exit configuration or of an exit direction sign may be the first indication that a driver has that he is approaching an exit.
$t_{\text {pre }}$ (time to perceive and read the exit direction sign) and $t_{\text {rse }}$ (time to read the exit direction sign) correspond to $t_{\mathrm{pra}}$ and $t_{\mathrm{rsa}}$ for the exit direction sign. $t_{\mathrm{rae}}$ represents the action at the exit.

The foregoing examples represent two of the many sequences analyzed and diagrammed.

Following the diagramming of the sequence, each sequence was analyzed frame-by-frame from the start of the sequence to its finish. All information available to the driver, and where it appeared, was identified, whether or

| REGISTER READING |  | SEqUENCE NUMBER | description of segment | applicable Figure | "LAMOMARK" | SYMBOL |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Stabt | FINISH |  |  |  |  |  |
| 00182 | 00508 | 4 | PT. Hand exit sequerseto $1-\frac{x}{x}$ perception of sign | D | $\left\|\begin{array}{c} \text { "EFLAND"exit } \\ \operatorname{sign}(a d v) \end{array}\right\|$ | Stact of $t_{\text {PRW ( }}$ (508) |
| 00508 | 00540 | 4 | RT. Hand enit sequencefrom Ist peecegtion of aign to sign readable | D | "EFLAND"enit $\operatorname{sign}(a d v)$ | ${ }^{\text {t PRW }}$ (508-540) |
| 00540 | 00597 | 4 | PT. Hand exit sequencefrom sign readable to fuell comprekension | $D$ | "EFLAND"exit sign (adw) | Stast of ${ }^{t}$ RSW ( 597 ) |
| 00597 | 00669 | 4 | RT. Hand exit sequence from full comprekension to out of briew | D | "EFLAND"exit -sign (ader) | tPRSW (597-669) |
| 00987 | 01039 | $4$ | RT. Hand exit sequence to 1 at perceptibnopign | D | "EFLAND"enit sign | Stact of tPRE(1039) |
| 01039 | 01081 | 4 | RT. Hand enit requence from 1 ot perception of sign to sign reading | D | "EFLAND"eait -sign | tPRE (1039-0181) |

Figure A-8. Format for over-all system analysis (example).
not the presented information was applicable to the specific sequence.

In addition to determining what information was available and where it was presented, a determination was made as to whether the information was formally aided (e.g., signs, markings, delineations), quasi-aided (e.g., guard rails, tree lines), or unaided (actual perception of event).

The information needs of the driver, and where they occurred were determined using the "Inventory of Information Needs" (Tables 3 through 10) as a checklist for each sequence.

The information needs were compared to the information available to determine whether and how the information needs of the user were satisfied. In addition, the area off the traveled path was analyzed to identify any horizontal clearance restrictions and to check for the availability of escape routes.

All instances of non- or partial satisfaction of needs, unusual maneuvers, violations of driver's expectancies and horizontal clearance restrictions off the traveled way were noted, and possible rectifications or changes were suggested.

The format used for this portion of the analysis is shown in Figure A-9.

## Between-Sequence Analysis

The between-sequence analysis was performed to determine the interactions between the sequences. As pointed out, the task of driving is actually a series of sequences that can compete for the driver's attention when more than one sequence occurs in a given time span or in very close temporal and spatial contiguity. The greater the number of sequences occurring together in a short time span, the more likely is the probability of driver overload, confusion, and subsequent error.

Thus, one way to identify areas of potential driver overload or confusion for a given section of road is to determine where, and how much, interaction of sequences occurs. In addition, a determination of temporal and spatial relationships can be gained from this type of analysis.

The way in which this goal was achieved was a graphic technique whereby the sequences were plotted on a timedistance representation of the test site. Vehicle speed, frame counts, and known fixed landmarks were used to derive the time-distance relationships.

Using these relationships, the sequences analyzed by the within sequence analysis were plotted. By way of illustration, a plot of a segment of I-85 is shown in Figure A-10 and represents the beginning of the test run on I-85 toward Durham, N.C.

## I 8 NORTHBOUND IMFORMATION ANALYSIS

(A) SEQUENCE \# $\frac{4}{}$ REGISTER 508 to 1342
(B) DESCRIPTION OF OVERALL SEQUENCE: EFLAND EXIT Sequence fram 1 at fencepion of EXIT wermisqg aigrito Lence of EXIT (see pigere $A-7$ )
(C) "SUB-LOOPS" OF OVERALL SEQUENCE See fiqume A-7 tpRW (508-540); atant of tRSW (540-597); tRSW(597-669) $t$ PRE (1039-1081); \&Tant \% $\pm$ RSE (1081-1122); tRSE (1122-1293) tRAE (1081-1308); tAC (540-1308); tatal sepuerice(508-1343)
INFORMATION AVAILABLE: Sigr Corses into creen t pepher readeble reade "EFLAND EXIT iMILE" \&"GAS"-Bilecenidisoff the rand irxicate a erunce of GAS \& LODEINGS(1037-1085) at EXIT Cos higuration"EFLAND $\pi^{\prime \prime} C^{\prime \prime G A S " ~ s i g n ~ R e e n ~}{ }^{\text {G }}$ visual perception of exit corfinuration aleo off line perception of
 wuked evide cepuence. $\qquad$

$\longrightarrow$

$\qquad$
(D) COMMENTS The sequeres descrichet throughout is only, cormenzed with haoro performa nee activitier and doed mot analyge axigtherig liblow macho ferfformance level. This Requence cickectec the foilowing icitiationd sequencer : $3 ;(5 ; 6 ; 7$ g eckanan
$\qquad$

185 NORTHBOUND INFORMATION ANALYSIS (SEQUENCE \#4)
(E) INFORMATION \& INFORMATION NEEDS SATISFACTION


Figure A-9. Format for within sequence analysis.


185 NORTHBOUND INFORMATION ANALYSIS (SEQUENCE \#4)
INFORMATION \& INFORMATION NEEDS SATISFACTION.


Figure A-9. (continued).


Figure A-9. (continued).

. . . . . . . Vertical alignment change
XXXXXXX CHANGE IN CROSS SECTION
000000 EXIT
$\Delta \Delta \Delta \Delta \Delta$ ENTRANCE
Figure A-10. Between sequence analysis.

## APPENDIX B

## DESCRIPTION OF TEST SITE *

## NEED FOR TEST SITE

The original portion of NCHRP Project 3-12 ended with, among others, two tangible outputs:

1. A procedure for the systematic design of information systems.
2. A procedure for checking the adequacy of signs for conditions of nighttime use.

Among the recommendations for future research and development, made at the conclusion of that initial phase, were the following:

1. Apply and modify/validate the Information System Application Procedure.
2. Extend and refine the proposed procedures for sign design.

When the plans for the continuation of the research effort were drawn up, it was felt that these two goals could best be met by selecting an actual, representative stretch of highway and applying the information system design and sign design procedures thereto.

The initial step in the continuation research effort, therefore, consisted of developing a set of site selection criteria, and locating a section of highway that met these criteria. This appendix reports on these activities and describes the site finally selected. Its primary purpose is to furnish background to the discussions of information systems and of the legibility of signs in Part I of this report.

## SITE SELECTION CRITERIA

The criteria adopted for the selection of a site are given in the following:

1. Interstate with parallel or contiguous U.S. highway.
2. Interstate signed in accordance with the manual.

3 . $\approx 25$-mile length in single state.
4. Mix of rural and urban areas.
5. Mix of geometric configurations.
6. Mix of commercial traffic.
7. Appreciable hourly traffic variations.
8. Varied interchange spacing and types.
9. No extremes of bad weather.
10. Responsible administrative agency.
11. Availability of required data.
12. Location selected to minimize cost.

The primary goal, leading to the adaption of these criteria, was to select a site that would represent good average practice throughout the United States.

For this reason a modern Interstate highway, signed

[^32]substantially in accordance with current standards, was desired. For purpose of comparison an adjoining or parallel section of rural arterial was also necessary. Although there is no doubt that information transmission and reception problems occur in their most acute form on urban arterial highways, it was believed that neither the state of the art nor the time and budgetary limits of this project would allow the initial applications of the newly developed procedures to be made to the worst case.

A length of approximately 25 miles was deemed to be the best tradeoff possible between the length that could be handled within the time and funds allocated and the length that would yield the required variability in abutting land use, geometric configurations, and interchange spacing. Furthermore, an appreciable proportion of commercial and out-of-state traffic was desired, combined with appreciable daily variations in traffic.

To perform the research study the necessary traffic data had to be available and the administrative agency in responsible charge of the selected highway had to be willing to cooperate in the research effort. Finally, to meet time and cost limitations, the selected site had to be one that allowed data collection to be carried out during the entire year and one that would minimize the travel costs to the site from the research agency's headquarters.

It was obvious that adoption of and adherence to this set of criteria would introduce certain limitations into the output of the research effort. The development of the procedures would not be tested against extremes in either climatic conditions or roadway design. Extremes in information challenge were not likely to be encountered in a test section meeting these requirements. However, it was believed that any procedure developed and tested on such a section would be applicable to the greatest part of the rural freeway and arterial highway mileage in the United States and that extensions of the procedures to extreme conditions, and to conditions likely to be encountered in the denser sections of the urban network, should be left to a future research effort that could use the results of the present effort as a starting point.

## DESCRIPTION OF TEST SITE

## Selection of Site

The requirements of no climatic extremes and minimum travel costs indicated that the first efforts to find an acceptable site should concentrate on the southeastern states. Accordingly, and working with the advice of the Office of Traffic Operations of the Bureau of Public Roads, sites in the States of Florida, South Carolina, North Carolina, and Virginia were investigated.

The site finally selected, as coming closest to meeting
the aforementioned criteria, is located in North Carolina. It consists of sections of I-85 and US 70, located in Durham and Orange Counties, hetween Durham and Greensboro. Figure B-1 shows the general area of the sile; Figure B-2 shows a more detailed view.

## General Site Characteristics

The site is located in the Raleigh-Durham-Greensboro crescent in the east-central area of the state. It is the government and educational center of the state and, except for Charlotte, contains the highest concentration of


Figure B-1. Study site-general area.


Figure B-2. Study site.
business and industrial establishments. The climate is moderate, with no snow problem. Heavy fog does occur, however, on an average of 34 days a year. Table B-1 gives the climatological data for Raleigh-Durham Airport, approximately 15 miles east of the east end of the test section. The data are sufficiently similar to data for the GreensboroHigh Point-Winston-Salem Airport, approximately 45 miles west of the west end of the test section, to be applicable to the entire section.

The eastern quarter of the test section is located within the city limits of Durham. The 1960 population of the City of Durham was 78,302; that of the Durham Standard Metropolitan Statistical Area (Durham and Orange Counties), 155,000 . A 10 percent population increase for the SMSA has been estimated for the period 1960 to 1965.

## Traffic Characteristics

Table B-2 gives a general summary of pertinent site characteristics. Blank spaces in the US 70 column indicate inapplicable items or unavailable information. Figures B-3 and B-4 show detailed traffic data for I-85. The count station was located approximately 20 miles west of the west limit of the section. Figures B-5 and B-6 show similar data for US 70. The count station for US 70 was located just west of the west end of the study section.
Figure B-7 is taken from a survey of rural speeds made by the North Carolina State Highway Commission. Station No. 12 is on I-85, approximately 18 miles west of the west end of the test section. Stations 30 through 33 represent other Interstate locations. Station 31 is located in the same general area and has the same general speed characteristics. The speed limit at the checkpoint is 65 mph . Figure B-8, taken from the same survey, shows additional data for
the test section. Stations 22 through 25 are in or near the test section. It should be noted, from this figure, that the Interstate part of the test section is representative of Interstate roads in North Carolina. It might also be worth noting, in this connection, that the average speed on completed sections of Interstate highway, throughout the United States, is 62.8 mph . Computer printouts of accidents for the test section, obtained from the North Carolina authorities, showed the expected bunching of accidents near and at interchanges, but no statistically significant high rates for any particular segment of the test section.

Existing signing on I-85 is discussed in Chapter Three of this report.* No statistical survey was made of existing signing on US 70 over and above the data taken from the film for purposes of information analysis. US 70 is signed, generally, in accordance with the applicable manuals, although a lower level of sign maintenance than that which prevails on I-85 was noted. At the three locations where US 70 intersects $\mathrm{I}-85$ modified interstate type signing is used on US 70. The portion of US 70 included in the test section contains one at-grade railroad crossing, no traffic signals, and several channelized at-grade intersections.

## Driving Population

Discussions with North Carolina driver licensing and driver education authorities revealed no significant differences, in either of these areas, from average United States practice. Although median school years completed for North Carolina are 8.9, as against a national average of 10.6, it was believed that this figure was distorted by

[^33]TABLE B－1
CLIMATOLOGICAL DATA


NORMALS，MEANS，AND EXTREMES

|  | Temperature |  |  |  |  |  |  |  | Precipitation |  |  |  |  |  |  |  |  |  |  |  | Relative humidity |  | Wind＊ |  |  |  |  |  |  | Mean number of days |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Normal |  |  | Extremes |  |  |  |  | $\begin{aligned} & \overline{\overline{0}} \\ & \frac{0}{\pi} \\ & \frac{1}{i} \\ & \frac{1}{2} \end{aligned}$ |  | $\stackrel{\text { a }}{\sim}$ |  | $\stackrel{\text { a }}{\sim}$ |  | $\stackrel{\text { \％}}{ }$ | Snow，Sleet |  |  |  |  |  |  |  |  | Fastest mile |  |  |  |  |  |  |  |  |  |  |  |  |  |
| （a） |  |  | $\begin{aligned} & \text { 亲 } \\ & \text { 唇 } \\ & \hline \text { (b) } \end{aligned}$ |  | $\stackrel{\text { a }}{\sim}$ | $\left\lvert\, \begin{array}{r\|r} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{array}\right.$ | $\stackrel{\text { ® }}{\substack{\text { ® }}}$ |  |  |  |  |  |  |  |  | $\begin{aligned} & \frac{\mathrm{t}}{\frac{0}{2}} \\ & \frac{\partial}{\mathrm{y}} \\ & \frac{2}{2} \end{aligned}$ |  | $\stackrel{\square}{\circ}$ |  | $\stackrel{\text {－}}{\sim}$ |  |  | $\begin{aligned} & \text { O } \\ & \text { id } \\ & \text { in } \end{aligned}$ |  |  | － | 8 |  |  |  |  |  |  |  | x． | － | n |
| （a） |  | （b） | （b） |  |  | 4 |  | （b） | （b） | 24 |  | 24 |  | 24 |  | 24 | 24 |  | 24 |  |  | 4 |  | 19 | 14 | 15 | 5 |  | 14 | 19 | 20 |  |  |  |  |  |  |  |  |
| F | 54 | 31.3 31.9 | 41.6 | 77 | 1965 | 8 | ${ }_{\text {cki }}^{1968}$ | 25 | 3.22 3.23 | 7.52 5.75 | 19964 | 2．05 | 1956 1968 | 2.79 <br> 2.40 | 2954 1946 | 3.2 | 14.4 | 1995 | 9.0 | 19664 |  |  | 8.5 | 5 | 40 |  |  |  |  | 10 | 14 |  |  |  |  |  |  |  |
| ${ }_{4}$ | ${ }^{61.1}$ | 37．8 | 49，5 | 89 | 1968 | 37 | ${ }^{1965}$ | 487 | ${ }_{\text {3 }}^{3.23}$ | 5．94 | 1960 | $1{ }^{1.4} 8$ | 1949 | 2．90 | 19920 | 221 | 13.5 | 1948 | ${ }_{7} 9$ | 1989 | 65 67 | ${ }_{7} 72485$ | 9.1 | SM | 40 | 22 | 1966 | 57 | 6：0 | 9 | 13 |  |  |  | ： |  | 22 | $\bigcirc$ |
| ${ }_{4}^{4}$ | 79.4 | 45．7 | 397．3 | ${ }_{92}{ }_{9}$ | ${ }^{1967}$ | ${ }_{3}^{28} 1$ | 1969 1968 | 180 34 | 3．52 | 3.83 6.69 | 1950 | $\xrightarrow{1.51}$ | 1965 | 2.02 <br> 4.40 <br> 1 | 1997 | \％ | 1 | 1950 | i | 1950 | ${ }^{1} 7478$ |  | 9．6 | ${ }_{\text {sk }}^{\text {SN}}$ | 4 | 14 | 1967 | ${ }^{64} 6$ | 5．8 ${ }^{5.6}$ | 10 | $1{ }_{11}$ |  |  |  | $\stackrel{\square}{0}$ |  | 1 | ${ }^{\circ}$ |
| 」 | 86.3 | 63.9 | 75.1 | 9 | 1968 | ${ }_{43} 1$ |  |  | ${ }_{3.70}$ | ${ }_{8.32}$ | 1965 | 1－12 | 1954 | 4.40 | 1967 | 0 | －0：0 |  | 0：0 |  | ${ }^{83} 86$ | ${ }^{5} / 545$ | 7：a | sw | 40 <br> 20 <br> 4 | 25 | 1960 19 | ${ }_{58}$ |  | ${ }_{8}^{8}$ | 12 | ${ }_{10}{ }^{9}$ |  |  | 1 |  | 1 |  |
| $\underset{A}{\wedge}$ | ${ }_{8}^{88.1}$ | 67.6 60.7 | 77.9 | ${ }_{98}^{97}$ | ${ }_{1968}^{1966}$ | ${ }^{5} 51$ | 1965 | － | 5.49 | 10.05 | 1945 | 0.80 | 1953 | 3.89 | 1952 | 0.0 | 0.0 |  | 0.0 |  | 88｜90 | 160 | 6.7 |  | 69 | 23 |  | 63 |  |  |  |  |  |  |  |  |  |  |
| ${ }_{s}^{A}$ | ${ }^{82}$ | 60.4 | 71.2 | 92 | 1955＊ | $4_{2}$ | 997 | 21 | S．${ }_{\text {S．}}$ | 120．94 | 1945 | － | 1954 | 5.20 5.26 | 1955 | －0．0 | 0．0 |  | 0.0 |  | 898 | 16075 | 6.6 |  | 40 | 29 | $1963+$ | 63 | 5.8 |  |  | 12 |  |  |  | ： | \％ |  |
| N | 72：8 | 48 | 50．5 | ${ }_{81}^{89}$ | 1968 | 24 217 | ${ }_{9} 965$ | ${ }_{4}^{164}$ | 2．71 | 1.53 8.52 8.22 | 1989 198 | － 4.4 | ${ }_{1963}^{196}$ | 4.10 | 1954 | －0．0 | －0．0 |  | \％．0 |  |  | （1）${ }^{5}$ | 7．0 | $\mathrm{NE}_{\mathrm{NNE}}$ | ${ }_{73} 3$ | 1 | ${ }_{1}^{1958}$ | 618 6 |  |  | 11 |  |  |  | 2 | － | ． |  |
| － | 52.3 | 31.4 | 41.9 | 75 | 1967 | 111 | 964 | 716 | 3.02 | － 8.20 | 1945 | 0.25 | 1965 | 3．18 | ${ }_{1958}^{195}$ | －0．21 | $\xrightarrow{10.3}$ | ${ }_{1958}^{1962}$ | ${ }_{9.1}^{1.3}$ | ${ }_{1}^{1968}$ | （25 |  | 7.8 | Sk | 30 | 36 | 1962 |  | 3.1 | 12 | 10 |  |  |  | ： |  | ${ }^{2}$ |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ${ }^{6}$ |  |  | 35 |  |  |  |  |  |  |  |  |  |  | － |  | － |
|  | 0． 8 | 48.3 |  | 98 |  |  |  | 3393 |  |  |  | 25 | 265 | 20 |  | 7.4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |






TABLE B-2
STUDY SITE CHARACTERISTICS

|  | Characteristics, by route |  |
| :--- | :--- | :--- |
|  | $\mathrm{I}-85$ | US 70 |
| ITEM | 20.2 | 9.0 |
| Length (miles) | 4 | 2 |
| No. of lanes | 12 | 10 |
| Lane width (ft) | 30 and variable | None |
| Median (ft) | 18,000 | 2,500 |
| AADT | 63.0 | - |
| Avg. speed (mph) | 3.52 | 2.96 |
| Acc/mi/yr | 14 | - |
| No. of interchanges | 1.6 | - |
| Avg. interchange spacing (miles) | 28.6 | 25.1 |
| \% commercial |  |  |
| $\%$ out of state |  |  |

abnormally low figures for the western part of the state. It was therefore assumed that, as far as educational achievement and intelligence are concerned, the local driver within the test section could be considered analogous to the median driver as defined in this report.

Table B-3 gives the distribution of North Carolina drivers by age and by sex. It can be noted that the median North Carolina driver is somewhat younger than the national average. This is not surprising, because the median age of the North Carolina population is 25.5 years, as against a national median of 29.5 years. However, it is believed that this difference is not significant for the design of an information system.

It must also be kept in mind that North Carolina

TABLE B-3
LICENSED DRIVERS IN NORTH CAROLINA (1966 DATA)

|  | NORTH <br> CAROLINA | UNITED <br> STATES |
| :--- | :---: | :---: |
|  | (a)Distribution by Age |  |
| 16 and under | 1.9 | 1.5 |
| 17 | 2.5 | 2.3 |
| $18-19$ | 5.1 | 5.2 |
| $20-24$ | 13.9 | 12.0 |
| $25-34$ | 23.8 | 20.6 |
| $35-44$ | 21.6 | 20.9 |
| $45-54$ | 16.2 | 17.7 |
| $55-64$ | 9.7 | 12.1 |
| $65-74$ | 4.4 | 7.8 |
| 75 and over | 0.9 |  |


|  | $(b)$ Number |  |
| :--- | ---: | ---: |
| Male | $1,457,000$ | $59,455,000$ |
| Female | 973,000 | $41,504,000$ |
| $\quad 2,430,000$ | $100,959,000$ |  |
| Total | 59.9 | 58.9 |
| Male (\%) | 48.6 | 51.2 |
| \% of population | 71.1 | 69.3 |
| \% population 18 |  |  |
| $\quad$ and over |  |  |

exhibits considerable demographic differences between the Piedmont region, where the test section is located, and the mountainous western portions of the state. Application of statewide figures to the test section may, therefore, be somewhat misleading. It is probable that the industrial Piedmont area is closer to national norms than is the state as a whole.

Therefore, it can be assumed that, for purposes of this study, the median North Carolina driver is analogous to the median United States driver. No data are available concerning visual attributes. The minimum visual acuity requirement for a driver's license in North Carolina is 20/60, which is somewhat lower than the national average. [The modal requirement is 20/40 (30 jurisdictions), with a total of 39 jurisdictions requiring $20 / 50$ or better.] In view of the younger median population and driving population, however, it is believed that the North Carolina median driver does have 20/20 vision. Insofar as driving exposure is concerned, the last of the listed median driver attributes, no exact data are available. However, from the fact that North Carolina drivers represent 2.22 percent of all United States licensed drivers and that the total mileage driven in North Carolina represents 2.36 percent of the total mileage driven in the United States, it can be deducted that median North Carolina driving exposure falls within the limits established for the United States median driver.

## A PRIORI AIDS

A description of a proposed simulated trip, including Durham and Greensboro, with a request for routing and other information, was sent to the American Automobile Association (AAA), seven oil companies, the Chambers of Commerce of Durham and of Greensboro, and the Department of Conservation and Development of the State of North Carolina. Prompt replies were received from all of these organizations.

The AAA sent a standard Triptik indicating I-85 as the preferred route between Greensboro and Durham, with no special or unusual information concerning this route. The two Chambers of Commerce sent city maps and general information concerning the cities, but no highway maps or other driving or trip-planning aids. The state agency sent a colorful brochure on the State's attractions, the official state map, and a listing of current events.

Six of the seven oil companies sent standard highway maps on which I-85 had been marked in colored ink. Five of these maps were of North and South Carolina, but represented only three different maps. Three oil companies used identical maps with different logos and other incidental artwork. One oil company sent a map that included Georgia with the two Carolinas; however, due to larger sheet size, the scale was comparable to the others. The scale on these six maps ranged from $1 \mathrm{in} .=15.6$ miles to 1 in . $=20.0$ miles.

Only two of these six maps, and the official state map, had details of Durham. Although the state map identified the location of interchanges (which the other two did not) it gave no clue as to the configuration of these interchanges.

The last oil company sent an atlas-type set of maps on

COUNTY
MONTH \& YE

| ate | $\begin{gathered} \text { bAr } \\ \text { Of } \\ \text { WX } \end{gathered}$ | $\begin{aligned} & 12-1 \\ & A M \end{aligned}$ | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | $8-9$ | 9.10 | 10-11 | 11-12 | ${ }^{12-1}$ |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 1 | 465 | 435 | 195 | 135 | 105 |  |  |  |  |  |  | 11.12 | PM | 1.2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7.8 | 8-9 | 9-10 | 10.11 | 11-12 | IOT |










$\qquad$

$\qquad$


| 14 |
| :---: |



$\qquad$
















## 17818 <br> 22720 -

weikdar aveiag
Figure B-3. Traffic count data, I-85.

| 19726 | 31 | 6142 |
| :---: | :---: | ---: |
| MONTHLY AVERGE | MONTHIY. |  |

satuday averace

NORTH CAROLINA STATE-WIDE HIGHWAY PLANNING SURVEY
AUTOMATIC TRAFFIC RECORDER DATA

Anni:a! Summary by Months for the Year 1968
County $\qquad$ Route No. I-85 No. 42 Loop Detector

Location 2.8 Miles W. of Alamance County Line.
Predominant Type of Traffic Interstate, Intrastate, Industrial commercial route.
Average Weekday Traffic Composition /1
Percent Total Passenger Cars $\quad 75.0$ Percent 0.0.S. Passenger Cars 23.0
Percent Total Conmercial Vehicles 25.0 Percent TTST 13.2
Remarks One of the principal Interstate and Intrastate routes. Main traffic
route through the Industrial Piedmont Section.

| MONTH | MACHINE |  | Percentage Daily Average is of Average Weekday | Percentage Daily Average Month to Year |
| :---: | :---: | :---: | :---: | :---: |
|  | Average Weekday/2 | Daily <br> Average |  |  |
| January | 17249 | 17216 | 100.2 | 84.9 |
| February | 16749 | 17434 | 96.1 | 86.0 |
| March | 18061 | 18852 | 95.8 | 93.0 |
| April | 19405 | 19600 | 99.0 | 96.7 |
| May | 19514 | 20134 | 96.9 | 99.3 |
| June | 21364 | 22374 | 95.5 | 110.3 |
| July | 21910 | 22732 | 96.4 | 112.1 |
| August |  |  |  |  |
| September | 20683 | 21602 | 95.7 | 106.5 |
| October | 19870 | 21382 | 93.4 | 10.5 .5 |
| November | 20755 | 21293 | 97.5 | 105.0 |
| December | 19820 | 20417 | 97.1 | 100.7 |
| Daily Average Eor Year | 19800/3 | 20500 | 96.6 | 100.0 |

L1 Based on Composition counts.
12 Average of all days of the month except Saturdays and Sundays.
13 Adjusted average for the year.

NOTE: As indicated by
Figure B-4. Annual traffic summary, I-85.

## HIGHWAY COMMISSION

41

US 70 AT ENO RIVER W. OF HILLSBORO
LOCATION
planning department
in cooperation with bureau of public roads
ORANGE
$10 / 67$

COUNT
MONTH 8 Y

| ate | $\begin{aligned} & \text { ony } \\ & \text { ory } \\ & \hline \text { wk. } \end{aligned}$ | $\begin{aligned} & 12.1 \\ & \mathrm{AM} \\ & \hline \end{aligned}$ | 1-2 | 2-3 | 3.4 | 4-5 | $5-6$ | 6.7 | 7-8 | $8-9$ | 9.10 | 10-11 | 11-12 | 12-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6 | 7-8 | 8.9 | 9.10 | 10.11 | 11-12 | T0 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 1 | 65 | 25 | 15 | 5 | 5 | , | 15 | 25 | 35 | 85 | 115 | 115 | 165 | 195 | 225 | 225 | 285 | 315 | 235 | 235 | 135 | 135 | 75 | 45 | 27 |
| 2 | 2 | 25 | 15 | 5 | 15 | 15 | 5 | 95 | 145 | 135 | 135 | 85 | 145 | 155 | 145 | 165 | 185 | 215 | 195 | 165 | 125 | 75 | 65 | 55 | 45 | 27 |
| 3 | 3 | 15 | 15 | 5 | 5 | 5 | 15 | 105 | 145 | 135 | 135 | 125 | 155 | 125 | 135 | 155 | 165 | 245 | 205 | 185 | 125 | 85 | 65 | 45 | 35 | 24 |
| 4 | 4 | 15 | 15 | 5 | 5 | 15 | 15 | 105 | 125 | 155 | 125 | 115 | 125 | 135 | 125 | 135 | 205 | 215 | 205 | 165 | 145 | 85 | 75 | 55 | 45 | 24 |
| 5 | 5 | 15 | 25 | 5 | 5 | 15 | 5 | 85 | 155 | 125 | 115 | 115 | 125 | 125 | 135 | 155 | 215 | 215 | 195 | 185 | 145 | 85 | 85 | 45 | 45 | 24 |
| 7 | 6 | 15 | 15 | 5 | 5 | 5 | 5 | 105 | 155 | 155 | 135 | 145 | 165 | 125 | 165 | 185 | 275 | 275 | 215 | 235 | 185 | 145 | 115 | 115 | 85 | 30 |
| 7 | 7 | 65 | 35 | 15 | 5 | 15 | 25 | 65 | 105 | 105 | 155 | 215 | 205 | 225 | 195 | 215 | 185 | 185 | 205 | 205 | 225 | 155 | 115 | 125 | 125 | 31 |
| 9 | 2 | 45 | 15 | 15 | 5 | 5 | 25 | 115 | 185 | 165 | 5 |  |  | 175 | 185 | 185 | 235 | 245 | 305 | 215 | 195 | 135 | 85 | 75 | 45 | 26 |
| 10 | 3 | 15 | 15 | 5 | 15 | 5 | 15 | 125 | 175 | 145 | 135 | 145 | 145 | 145 | 75 |  |  | 27 | 215 | 155 | 95 | 55 | 45 | 55 | 45 | 25 |
| 11 | 4 | 15 | 5 | 5 | 5 | 5 | 1.5 | 125 | 165 | 145 | 125 | 135 | 135 | 125 | 1.15 | 135 | 95 |  |  | 135 | 105 | 75 | 55 | 45 | 45 | 26 |
| 12 | 5 | 25 | 15 | 5 | 5 | 5 | 15 | 115 | 155 | 145 | 125 | 145 | 145 | 135 | 135 | 155 | 225 | 235 | 215 |  | 05 | 75 | 55 | 45 | 45 | 23 |
| 13 | 6 | 15 | 15 | 5 | 15 | 35 | 55 | 115 | 135 | 135 | 165 | 165 | 185 | 165 | 155 | 175 | 195 | 265 | 175 | 215 | 175 | 5 | 5 | 65 | 55 | 250 |
| 14 | 7 | 55 | 35 | 5 | 15 | 15 | 45 | 65 | 95 | 105 | 155 | 195 | 215 | 215 | 235 | 185 | 215 | 205 | 205 | 205 | 225 | 145 | 85 | 5 | 5 | 29 |
| 15 | 1 | 75 | 45 | 25 | 15 | 15 | 15 | 25 | 45 | 35 | 85 | 105 | 125 | 175 | 205 | 195 | 235 | 255 | 305 | 275 | 225 | 135 | 115 | 95 | 55 | $1{ }^{1}$ |
| 16 | 2 | 25 | 15 | 5 | 15 | 5 | 25 | 115 | 165 | 145 | 135 | 125 | 145 | 165 | 155 | 145 | 215 | 235 | 225 | 165 | 135 | 75 | 65 | 45 | 35 | 25 |
| 17 | 3 | 15 | 15 | 5 | 5 | 5 | 15 | 115 | 175 | 125 | 105 | 125 | 115 | 135 | 135 | 155 | 195 | 225 | 215 | 155 | 125 | 85 | 75 | 55 | 45 | 24. |
| 18 <br> 19 | 4 | 15 | 15 | 5 | 5 | 15 | 15 | 115 | 145 | 145 | 125 | 145 | 145 | 125 | 165 | 165 | 195 | 245 | 175 | 145 | 125 | 95 | 95 | 45 | 45 | 25 |
| 19 <br> 20 | 5 | 15 | 15 | 15 | 15 | 5 | 25 | 105 | 135 | 135 | 115 | 135 | 165 | 135 | 155 | 85 | 165 | 235 | 205 | 165 | 75 | 95 | 65 | 55 | 55 | 23 |
| 21 | 7 | 65 | 35 | 25 | 15 | 5 | 15 | 95 | 35 | 13 | 115 | 125 | 145 | 125 | 125 | 155 | 225 | 255 | 245 | 205 | 215 | 135 | 95 | 115 | 85 | $2 \hat{z}$ |
| 22 | 1 | 105 | 45 | 25 | 15 | 15 | 5 | 15 | 25 | 35 | 5 | 95 |  |  |  | 185 | 195 | 205 | 215 | 195 | 255 | 205 | 105 | 115 | 135 | 3 i |
| 23 | 2 | 25 | 5 | 5 | 5 | 5 | 15 | 85 | 145 | 145 | 115 | 135 | 135 | 5 | 125 |  |  |  | 295 | 265 | 215 | 135 | 85 | 85 | 55 | 28 |
| 24 | 3 | 15 | 5 | 5 | 5 | 5 | 15 | 115 | 155 | 145 | 165 | 125 | 125 | 125 | 145 | 145 | 205 |  | 215 | 155 | 115 | 75 | 55 | 55 | 45 | 24 |
| 25 | 4 | 15 | 5 | 5 | 5 | 5 | 15 | 115 | 95 | 145 | 135 | 125 | 95 | 125 | 145 | 155 | 175 | 195 |  | 145 | 105 | 75 | 65 | 45 | 45 | 24 |
| 26 | 5 | 15 | 15 | 5 | 5 | 5 | 15 | 105 | 125 | 135 | 115 | 105 | 105 | 135 | 135 | 145 | 215 | 215 | 205 |  |  |  | 65 | 45 | 45 | 21 |
| 27 | 6 | 15 | 15 | 15 | 5 | 5 | 5 | 95 | 125 | 155 | 115 | 115 | 165 | 155 | 155 | 175 | 235 | 225 | 265 | 195 | 215 | 5 | 5 | 5 | 45 | $\frac{23}{28 .}$ |
| 28 | 7 | 55 | 35 | 15 | 15 | 15 | 35 | 65 | 85 | 95 | 125 | 165 | 185 | 185 | 185 | 175 | 185 | 205 | 205 | 165 | 245 | 155 | 125 | 135 | 95 | 28 |
| 29 | 1 | 75 | 35 | 25 | 15 | 5 | 5 | 15 | 25 | 45 | 65 | 105 | 125 | 165 | 205 | 265 | 295 | 295 | 265 | 195 | 145 | 85 | 105 | 65 | 45 | 26 |
| 30 | 2 | 25 | 15 | 5 | 5 | 5 | 15 | 95 | 125 | 145 | 115 | 135 | 195 | 125 | 135 | 135 | 205 | 225 | 195 | 105 | 75 | 55 | 45 | 45 | 35 | 22 |
| 31 | 3 | 15 | 15 | 5 | 5 | 5 | 15 | 115 | 135 | 115 | 125 | 125 | 115 | 125 | 135 | 145 | 185 | 215 | 215 | 125 | 105 | 75 | 85 | 55 | 55 | 23 |

2512
Figure B-5. Traffic count data, US 70.

30952758 satumday average
sumbar averace

2630
31
o. oars

814

NORTH CAROLINA STATE-WIDE HIGHWAY PLANNTNG SURVEY AUTOMATIC TRAFFIC RECORDER DATA

Annual Summary by Months for the Year 1968
$\qquad$ Route No. US-70 No. 41 Tube

Location At Eno River W. of Hillsboro
Predominant Type of Traffic Comnuter and commercial route
Average Weekday Traffic Composition $/ 1$
Percent Total Passenger Cars_*_ Percent 0.O.S. Passenger Cars *
Percent Total Commercial Vehicles__ *__ Percent TTST___
Remarks US-70 a conmercial and commuter route paralleling Interstate 85.
$\qquad$ NUMBER OF VEHICLES

|  | MACHINE |  | Percentage Daily Average is of Average Weekday |  |
| :---: | :---: | :---: | :---: | :---: |
| MONTH | Average Weekday / 2 | Daily <br> Average |  | Percentage Daily Average Month to Year |
| January | 2208 | 2292 | 96.3 | 82.2 |
| February | 2313 | 2432 | 95.1 | 87.2 |
| March | 2498 | 2613 | 95.6 | 93.7 |
| April | 2446 | 2600 | 94.1 | 93.2 |
| May | 2553 | 2691 | 94.9 | 96.5 |
| June | 2655 | 2722 | 97.5 | 97.6 |
| July | 2649 | 2766 | 95.8 | 99.1 |
| August | 2859 | 3014 | 94.9 | 108.0 |
| September | 3081 | 3199 | 96.3 | 114.7 |
| October | 2965 | 3085 | 96.1 | 110.6 |
| November | 2986 | 3069 | 97.3 | 110.0 |
| December | 2976 | 3000 | 99.2 | 107.5 |
| Daily Average Eor Year | 2600/3 | $2700 \quad 13$ | 96.1 | 100.0 |

eor year
*
Composition counts.
12 Average of all days of the month except Saturdays and Sundays.
13 Adjusted average for the year.

NOTE: As indicated by_ * composition counts, the error in machine recording of vehicle is: $3.3 \%$ overcounting

* Composition Counts not made.

Figure B-6. Annual traffic summary, US 70.
which the scale of the North Carolina map was 1 in. $=35.6$ miles. This map had no city detail at all.

All the oil companies, in addition to sending promotional material, sent some kind of trip-planning guide. Generally, these contained chceklists of things to do before leaving home, with some of these conccrned with the mechanical condition of the vehicle. Other items included the availability of tourist information, first-aid tips, statewide speed limits, map-reading instructions, and similar information.

It is worth noting that:

1. None of the ten agencies contacted (which included a state agency) sent a copy of the North Carolina Driver's Manual or of the applicable North Carolina laws.
2. No copy of the North Carolina detour bulletin, issued regularly by the Highway Commission, was received.
3. No piece of information received would alert the driver that the interchange of eastbound I-85 with US 70 , near Efland, included a left-hand off-ramp.

## REFERENCES

B-1. Published and unpublished information furnished by North Carolina Highway, Education, Enforcement, and Motor Vehicle agencies.
B-2. Statistical Abstracts of the United States-1967. Dept. of Commerce, Bureau of the Census.
B-3. Baerwald, J. D., ed., Traffic Engineering Handbook.

> NORTH CAROLINA
> AVERAGE SPEEDS AT
> SPEED CHECK STATIONS
> SPRING- 1967


Figure B-7. Average speed data, 1-85.

2d ed., Inst. of Traffic Eng., Washington, D.C. (1965).

B-4. Highway Statistics-1965. U.S. Dept. of Trans.,

Bureau of Public Roads (1967).
B-5. Automobile Facts and Figures-1968. Automobile Manufacturers Assn., New York.

NORTH CAROLINA<br>AVERAGE SPEEDS AT<br>SPECIAL INTERSTATE SPEED CHECK STATIONS SPRING 1967

| Sta <br> No. | Location | County Eas | $\begin{array}{r} \text { Dire } \\ \text { bound } \\ \hline \end{array}$ | tion Westbound | Total |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 01 | $E$. of SR-1129 I-40 | Burke | 61.6 | 60.9 | 61.3 |
| 02 | $E$. of SR-1129 | Burke | 60.6 | 60.6 | 60.6 |
| 03 | W. of SR-1002 | Burke | 59.0 | 56.7 | 57.9 |
| 04 | E. of SR-1709 | Catawba | 58.3 | 59.1 | 58.7 |
| 05 | S. of SR-1502 | Iredell | 61.5 | 64.4 | 63.0 |
| 06 | S.W. of 64 Bus. | Iredell | 61.3 | 62.3 | 61.8 |
| 07 | N.E. of US 21 | Iredell | 60.5 | 61.8 | 61.2 |
| 08 | N.E. of NC-801 | Forsyth | 60.3 | 60.5 | 60.4 |
| 09 | S.W. of SR-1137 | Forsyth | 60.1 | 60.0 | 60.1 |
| 10 | N.E. of SR-1001 | Forsyth | 62.5 | 60.5 | 61.5 |
| 11 | S.W. of Int. US-158 | Forsyth | 60.2 | 60.3 | 60.3 |
| 13 | S. of SR-2643 | Forsyth | 61.2 | 61.0 | 61.1 |
| 14 | S.E. of SR-1858 | Guilford | 61.1 | 63.3 | 62.2 |
| 15 | N.W. of SR-1541 | Guilford | 58.6 | 58.7 | 58.7 |
| 16 | S.E. of NC-6 | Guilford | 61.6 | 56.4 | 59.0 |
| 17 | N.W. of Int. US-29 Byp. | Guilford | 55.6 | 57.1 | 56.4 |
| 18 | S.W. of US-1 | Warren | 62.8 | 63.1 | 63.0 |
| 19 | On I-85 W. of Warren Co. Line | Vance | 63.5 | 60.9 | 62.2 |
| 20 | N.E. of US-1 Byp. Int. | Vance | 63.8 | 63.0 | 63.4 |
| 21 | S.W. of SR-1317 | Vance | 60.0 | 60.2 | 60.1 |
| 22 | On I-85 W. Durham Co. Line | Orange | 60.7 | 62.0 | 61.4 |
| 23 | 0 O $\mathrm{T}=85 \mathrm{~W}$, nf $\mathrm{NC}-86$ | Orange | 62.1 | 57.9 | 60.0 |
| 24 | S.E. of SR-1144 | Orange | 60.9 | 61.0 | 61.0 |
| 25 | W. of SR-1144 | Orange | 63.9 | 62.1 | 63.0 |
| 26 | S.W. of SR-1225 | Davidson | 59.6 | 58.0 | 58.8 |
| 27 | N.E. of NC-150 | Davidson | 61.6 | 61.7 | 61.7 |
| 29 | S.W. of US-70 | Rowan | 61.8 | 58.9 | 60.4 |
| 31 | N.W. of Bus. NC-29 | Rowan | 62.1 | 60.9 | 61.5 |
| 32 | S.W. of Int. NC-49 | Mecklenburg | 57.4 | 55.2 | 56.3 |
| 33 | N.E. of Int. US-21 | Mecklenburg | 60.1 | 58.3 | 59.2 |
| 34 | N.E. of NC-16 | Mecklenburg | 60.3 | 58.4 | 59.1 |
| 35 | N.W. of SR-1662 | Mecklenburg | 62.0 | 62.6 | 62.3 |
| 36 | E. of NC-273 | Gaston | 61.0 | 59.5 | 60.3 |
| 37 | E. of NC-7 | Gaston | 64.6 | 61.0 | 62.8 |
| 38 | W. of SR-2200 | Gaston | 63.7 | 63.8 | 63.8 |
| 39 | W. of SR-1118 | Gaston | 63.7 | 58.6 | 61.2 |
| 40 | E. of SR-2245 | Cleveland | 63.7 | 62.6 | 63.2 |
| 41 | N.E. of NC-216 | Cleveland | 64.6 | 64.8 | 64.7 |
| 42 | S.E. of SR-2385 I-95 | Johnston | 63.3 | 58.1 | 60.7 |
| 43 | N.E. of SR-2303 | Johnston | 60.6 | 62.8 | 61.7 |
| 44 | N.W. of SR-1206 | Johnston | 63.0 | 60.7 | 62.9 |
| 45 | S.W. of SR-1211 | Johnston | 64.4 | 60.0 | 62.2 |
| 46 | US-421 SW | Harnett | 62.4 | 63.9 | 63.2 |
| 47 | N.E. of SR-1815 | Cumberland | 62.0 | 62.5 | 62.3 |
| 48 | S.W. of SR-1831 | Cumberland | 60.3 | 60.0 | 60.2 |
| 49 | S.W. of SR-2242 | Cumberland | 61.9 | 61.0 | 61.5 |
| 50 | W. of NC-20 | Robeson | 61.0 | 62.7 | 61.9 |
| 51 | W. of US-301 | Robeson | 62.9 | 65.4 | 64.2 |
| 52 | S. of NC-48 | N. Hampton | 63.3 | 63.6 | 63.5 |
| 53 | S.W. of NC-46 | N. Hampton | 61.9 | 60.3 | 61.1 |

Figure B-8. Speed data, Interstate highways, North Carolina.

## APPENDIX C

## COMPUTER PROGRAM DESCRIPTION—PROGRAM ROADSIGN *

One major attribute of a roadsign impacting directly on the safety and convenience of motorists is its legibility when illuminated solely by automobile headlights. Although the parameters affecting legibility are known, no test program has been carried out that will explore in sufficient detail the spectrum of possible environments, materials, and operating conditions resulting in measured legibility values.

In view of the importance of this determination, a computer program, called ROADSIGN, has been written to simulate a motorist driving a vehicle on a road at night with headlights on, and approaching a sign on the road. The program computes the luminance at the four corners and at the center of the sign as apparent to the driver of the vehicle traveling along an existing, proposed, or hypothetical highway and approaching the sign.

The simulation takes into account the following parameters, which together constitute the major influences on sign legibility:

1. Distance from sign.
2. Automobile headlight light output.
3. Sign material reflectance.
4. Highway alignment and profile.**
5. Sign location and attitude with respect to the highway.
6. Vehicle geometry.
7. Location of driver within vehicle.
8. Location of vehicle on the highway.
9. Atmospheric transmissivity.
10. Variations in vehicle voltage as they affect headlights.
11. Variations in sign reflectance as typically caused by aging and weathering.
12. Variations in headlight alignment.

ROADSIGN has been designed to take into account these factors with a high degree of flexibility. In addition, to accommodate future expansion, the program has been structured so that additional factors not considered part of the original simulation can be incorporated without revision to the basic program structure.

## INPUTS

Inputs fall into two categories: (1) stored inputs, and (2) program variable inputs. The former are part of the program as presently configured, but may be modified, expanded, or deleted via program modification. The latter are input via punched cards.

[^34]
## Stored Inputs

Table C-1 gives the program stored tables. The listed values were found to cover a large proportion of the cases of interest. For each simulation run the pertinent set of descriptions must be chosen via program control. The program will tabulate results for all distances stored without additional control.

## Program Variable Constants

Program variable constants are those parameters that are held constant for any one complete run, but that may be varied between runs by a simple input or command change. Program variable constants are input via punched cards (see "Running Instructions," which follows). They fall into the following categories and are derived as described in the following.

## Alignment

Horizontal.-The correct preparation of the horizontal highway alignment is extremely important. Because the distance traveled is determined by the difference in stations between the vehicle and the sign, a reference line should be chosen within the roadway of interest. Using this reference line will yield more accurate results than a center line or other line falling in a wide median or off the road. The stationing must be continuous and without station equations. Where spirals are included in the alignment, they should be replaced with simple curves or with a series of compound curves that approximate the curvature. Any resultant slight discrepancies will have little or no effect on the output values.

In preparing data for the alignment inputs, COGO * is useful but not necessary. The following alignment details are required:

1. Azimuth of the beginning tangent (for the sake of convenience, the first point of the alignment should be on a tangent; it can be a PC).
2. For each curve:
a. PC station.
b. PT (or PCC) station.
c. Radius (positive for curves to the right, negative for curves to the left).

The program can accommodate up to 98 curves.
Profile.-For the preparation of the profile, the stations must be in the same station system as those defining the horizontal alignment. The PVI station, the PVI elevation, and the vertical curve length are required. Storage is available for 98 vertical curves.

[^35]TABLE C-1

## DETAILS OF TABLES PERMANENTLY STORED

| table stored | COntents of table | USED BY |
| :---: | :---: | :---: |
| Isocandle distribution tables (candlepower) | \#6012 high-beam lamp <br> \#6012 low-beam lamp <br> \#4002 high-beam lamp <br> \#4002 low-beam lamp <br> \#4001 high-beam lamp | Two headlamps on vehicle <br> Four headlamps on vehicle |
| Specific luminance table (foot-lamberts/footcandle) | WAFT SILVER SCOTCHLITE ${ }^{a}$ <br> SIGNAL SILVER ${ }^{\text {a }}$ <br> \#908 buttons ${ }^{\text {b }}$ | Material code 1 |
| Distances, car to sign along road (feet) | $3,000,2,000,1,000$, $800,600,400,200$, $100,80,60,40$ | Lamp to sign distances in feet |

a Registered trademark, 3M Company.
${ }^{\text {b }}$ Registered trademark, Stimsonite Signal Products Corp.

## Signs

Signs are located by stations. Data to be obtained for each sign include the station, offset (positive to the right) with respect to the horizontal alignment reference line, sign material, dimensions of the sign, age of the sign, and the angle of rotation defining the skew angle.

## Vehicle Specification

Because sign brightness is a function of the geometric relationships between the sign, the car, the headlights, and the observer, the dimensions of the car and the driver's location therein must be specified.

This program uses a vehicle coordinate system originating halfway between the headlights and located on the road (Fig. C-1). This system is independent of the road coordinate system.

Required inputs include the absolute values describing the locations of the drivers' eyes and of all headlights within this coordinate system. Because headlight pairs are placed symmetrically about the vehicle coordinate system, one $Y$ and $Z$ value is required for each pair of lamps.

Table C-2 gives values used for this program to describe the four vehicles tested by the computer program. Dimensions are tabulated to the nearest thousandth of a foot for use as entry on the computer cards.


Figure C-1. Vehicle coordinate system.

TABLE C-2
DIMENSIONS OF VEHICLES USED IN PROGRAM

| vehicle | COORDINATES |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | DRIVER'S EYES |  |  | Main beam |  | aUxiliary |  |
|  | $X$ | $Y$ | Z | $Y$ | Z | $Y$ | $Z$ |
| Sedan w/horizontal headlamp configuration | 7.900 | 1.400 | 3.950 | 2.442 | 2.125 | 1.800 | 2.125 |
| Sedan w/vertical headlamp configuration | 7.900 | 1.400 | 3.950 | 2.692 | 2.616 | 2.692 | 2.050 |
| Compact car | 7.358 | 1.183 | 3.500 | 1.933 | 2.058 | 1.400 | 2.058 |
| Sports car | 7.358 | 1.183 | 3.500 | 1.179 | 2.125 |  |  |



Figure C-2. Program block diagram.

A negative $Y$ distance is used where a driver is located on the right side of a vehicle.

ROADSIGN can accommodate up to ten different vehicle types within the same run.

## Other Factors

In addition to the major parameters just discussed, other factors affecting sign brightness may be input via appropriately coded punched cards. They are:

1. Transmissivity of the air.
2. Age of the sign.
3. Vehicle voltage if different from nominal.
4. Degree of headlight misalignment.

## PROCESSING

The program operates as shown in Figure C-2. The logic functions, in general, so as to determine the location of vehicle headlights, driver's eyes, and sign (both center and corners) in orthogonal space. It then computes the distances between these three sets of points for each distance stored.

Using the distances computed as well as the inputs describing illumination levels, specific luminance, divergence and entrance angles, and other factors characterizing or affecting light level, the program calculates apparent sign luminance.

Here it uses the algorithms and functions described in detail in Chapter Three of this report.

Following each set of calculations, the program outputs results via the line printer.

Options available by means of selection of the proper control card include the choice of different vehicle types approaching the sign of interest, and/or the computation of a number of signs of the same or different configurations placed along the same highway.

## Program Structure

ROADSIGN is designed to run on an IBM 360/40 or larger computer. The program is structured with exceptional flexibility in that changes and modifications can be implemented with ease.

As presently configured, the program simulates 13 parameters influencing sign visibility. However, patching statements have been included so as to permit the incorporation into the logic of as many as 13 additional operation codes. This allows the inclusion of many additional parameters, without restructuring the logic. Thus, the simulation may be extended to investigate (with relative simplicity) the effect, for example, of vehicle operation with only one headlight.

The punched card input structure also maintains the flexibility principle. The number of road alignment descriptors, for example, is variable but may encompass as many as 98 curves. Individual cards are designed to accept essentially free-form information so that the user may select his own reference system or take advantage of existing station descriptors without the need to make the reference system conform to a fixed form and format.

Flexibility is also the guide to the treatment of stored inputs. Although it was found necessary, from the standpoint of operating efficiency, to maintain certain parameters as stored inputs, these also can be easily modified.

## Running Time

The following is an example of program operation and demonstrates typical running time requirements.

For one test of signing along an existing highway, a horizontal alignment containing 29 curves and a profile containing 56 curves were used. The sign table contained a total of 63 signs. The actual computer elapsed time required to calculate the luminance of all the 63 signs as the vehicle approached each sign from $3,000 \mathrm{ft}$ to 40 ft was 12 min and 47 sec . This time included reading in and checking the card inputs, storing the information, making preliminary calculations, dumping onto the printer these preliminary calculations, further checking, and finally outputting 63 pages of luminance values for two pairs of headlights for both high and low beam.

## Detailed Flow Diagrams

Figure C-3 shows the main-line program flow. Figures C-4 through C-7 show, in detail, the flow of the subroutines. All subroutines, as well as the main flow, are shown to the extent necessary to gain an understanding of program operation.

## Listing

Figure C-8 shows the listing for the program, and Table C-3 gives a glossary of forms used in the listing.*

## OUTPUTS

Outputs from ROADSIGN are in the form of hard-copy printouts. They fall into three general categories: (1) data that are output by the program as a minimum, (2) optional outputs that may be obtained by use of the appropriate control instruction, and (3) error messages that are generated when the program detects faults or inconsistencies in the input structure. Table C-4 gives the range of outputs available, referenced to the corresponding figure (Figs. C-9 through C-17)..**

## RUNNING INSTRUCTIONS

ROADSIGN is designed to run on an IBM 360/40 computer or larger, using FORTRAN G or H Compiler, operating under OS or DOS. Magnetic tape transports are not required. The input is processed on punched cards. The output is generated by the line printer, using output unit \#6.

The general procedure for preparing the input is shown in Figure $\mathrm{C}-18$. The resultant basic arrangement of the input deck is shown in Figure C-19. Figure C-20 shows

[^36]

Figure C-3. Main line program flow.





Figure C-3. (continued).







Figure C-6. (continued).



Figure C-7. Subroutine HLLUM.



Figure C-18. For minimum input required.


Figure C-19. Minimum input required for luminence of signs calculations-general arrangement of basic :nput deck.


TABLE C-4
PROGRAM OUTPUTS ROADSIGN

|  | FIG. |
| :--- | :--- |
| DESCRIPTION | NO. |
| Minimum: | C-9 |
| Input | C-10 |
| Computational data |  |
| Optional: | C-11 |
| Title page | $\mathrm{C}-12$ |
| Alignment stored | $\mathrm{C}-13$ |
| Profile stored | $\mathrm{C}-14$ |
| Table of signs stored | $\mathrm{C}-15$ |
| Vehicle specification stored | $\mathrm{C}-16$ |
| End page |  |
| Errors: | $\mathrm{C}-17$ |
| Error messages |  |

an expanded input deck that uses some of the typical options available to the user.

The individual card images available or required for program use are shown on Figures C-21 through C-35.*

[^37]
## APPENDIX D

## ON DETECTING THE ABSENCE OF INFORMATION NEED SATISFACTION *

At the beginning of this project it was postulated that the absence of information needs satisfaction, either complete or partial, could be detected by means external to the traffic stream. Analysis of drivers' information needs, reported on in Part I of this report, indicated that less than full satisfaction of information needs would lead to drivers' confusion. This confusion should give rise to a change in driving behavior and this change should be detectable. It was further believed that such detection methods were available and that, after a survey of the state of the art, an appropriate method could be selected and applied to the test section. According to the Work Plan for NCHRP Project 3-12/1:

The first series of activities that will be undertaken during this phase will be the review of previously used or advocated "confusion" detection methods, the selection of the method or methods most applicable and responsive to the requirements of this project, and the application of the selected method or methods to the particular site to develop data for use in the "Identification of Responsive Traffic Parameters Activity." The term "confusion detection" methods refers to methods that, either directly or indirectly, indicate that there is a problem inherent in the particular segment of roadway which may be attributable to a flaw in information presentation to the driver.

However, when this phase of the project was started it was soon determined that an existing appropriate method

[^38]could not be found. Therefore, it was decided to start a theoretical investigation of what perturbations in the traffic stream could be detected by normal sampling methods. This appendix reports on that work.

## EXISTING METHODS

Changes in drivers' gross overt behavior, reported on in the literature, have been studied for one of two purposes: these are (1) general studies of driving behavior, and (2) evaluation of drivers' reactions to certain specific traffic engineering measures. Excluded from this survey were all those studies that measured micro changes in driver behavior (e.g., steering-wheel reversals or acceleration noise) or drivers' physiological responses (e.g., GSR or eye movement) and required instrumentation of the car and/or the driver. Furthermore, the survey concentrated on those methods in which both the observer and the measuring equipment were located external to the vehicle and the vehicle was non-cooperative. Not considered further, therefore, were those methods that, although not requiring any special instrumentation, still required one or more observers to be physically present in the vehicle. A good example of this approach is represented by work done by the Road Research Laboratory ( $D-1$ ). This method uses, in its various forms, checklist
visual observation of 12 to 15 items by two or three observers riding in the test vehicle.

Five previous studies were identified as meeting the requirements of observers external to the traffic stream and non-cooperative vehicles. Studies whose methodology required elaborate photographic equipment for data collection were also rejected. It is not maintained that this search was complete; however, it is believed that the studies located, and mentioned subsequently, are representative, and that the conclusion drawn from this part of the project, that there is no existing methodology that can be used for the purpose expressed in the quotation from the work plan, is valid.

Of the five pertinent studies, three dealt with the design and effectiveness of pavement markings and delineation, one with the accident potential of intersections, and one with the effectiveness of directional signing. The three pavement marking studies were performed, respectively, in Michigan ( $D-2$ ), Minnesota ( $D-3$ ), and Oregon ( $D-4$ ). A fourth study of the same kind, made in Ohio ( $D-5$ ), was eliminated because it used elaborate photographic data collection methods.

The Michigan study was designed to evaluate the effectiveness of color in marking and delineating exits. The study methodology included the subjective determination of "erratic" driving maneuvers, according to a predetermined descriptive checklist. For the "before" part of the study, representing steady-state conditions, slightly more than 2 percent of all entering traffic for daytime conditions was found to engage in erratic maneuvers. For the purpose of the present project, one of the conclusions of that study is worth quoting. Talking about the description of an "erratic" maneuver, the report states:

> This classification could not detect this sort of maneuver or the confused or lost driver who may have appeared to an observer to be fully aware of his direction of travel.

The Minnesota study dealt with the evaluation of color systems in guiding traffic through highway interchanges. As in the Michigan study, "abnormal or erratic" behavior, in five predefined classes, was noted by observers. For steady-state conditions, between 1.07 and 4.32 percent of total traffic for daytime and between 3.12 and 7.83 percent of total traffic for nighttime was found to engage in these "abnormal and erratic" maneuvers.

The Oregon study also dealt with the effectiveness of color-coded freeway exits. It differs from the other two in that no subjective evaluation of observed driver behavior was included. The variables measured for both the "before" and "after" studies were lateral placement, speed, and accident experience. Within the context of this discussion it is of interest that no significant changes in either speed or accident rates were found after "confusion" was, presumably, decreased by the use of color-coded delineation and a significant difference in the "smoothness" of the exit path was noted.

The General Motors Research Laboratory (D-6) developed a method for systematically observing an intersection for traffic conflicts. More than 20 objective criteria
are defined for the guidance of the observers. As formalized in a Procedures Manual (D-7), the method calls for the observation of one intersection, by two men, throughout one $10-\mathrm{hr}$ day. The procedure appears to be promising for the investigation of high-accident locations. It is, however, time-consuming.

The one method identified that was directly applicable to signing problems was developed by Alan M. Voorhees and Associates for a study of signing of the Washington Beltway ( $D-8$ ). This method uses a team of two observers who note '"unusual drivers' actions" subdivided into seven categories. The unusual actions as a percentage of total traffic were then used as a comparative index of signing effectiveness. The study concluded that rates greater than 0.2 percent indicated a problem location. The study suggested further research, in depth, to explore the implication and applicability of this method. The original study was made in 1966; further research apparently has not been started.

## THEORETICAL INVESTIGATIONS

After these proposed methods were examined it was decided that none was appropriate to the present project or the study section selected, for reasons of cost, duration, subjectivity, or sensitivity. For the purposes of this project, and as a recommended adjunct to the "Information System Review Manual" of this report (Appendix H), a method was sought that would use one of the parameters of the traffic stream, capable of being measured by any traffic engineering organization, and that could be used, on a sampling basis, to detect locations where some drivers were "confused," presumably due to unsatisfied information needs. It was believed that the selected parameter could be represented by a probability distribution and that the response of some motorists to the "confusion," by altering the value of the selected parameter, would shift this probability distribution to an extent detectable by sampling.

Because no previously advocated technique was identified that would meet these criteria, it was decided to make a theoretical investigation of this problem under the following assumptions:

1. There is a probability function, or probability density function, $f(x)$, where $x$ represents any selected parameter of the traffic stream, with known mean, variance, and distribution.
2. For a proportion, $P$, of the population described by this function, the value of this parameter changes by $d x$, where $d x$ has its own probability function, $g(d x)$, with unknown mean and variance.
3. After completion of the individual changes in this parameter, the parameter will be distributed according to a new probability function, $h(x)$, with unknown mean and variance.

The problem thus consists of deriving a set of functions that will describe the relationships between $P$, the three means and variances, and the sample size, $n$, required to
be able to state, with a given degree of confidence, that a shift in the distribution has or has not taken place; that is, that a sample drawn from $h(x)$ can be demonstrated, statistically, as not coming from $f(x)$.

The problem was approached through computer simulation. It was assumed that the selected parameter (spot speed) was normally distributed with a mean of 50 mph and a standard deviation of 10 mph . A normally distributed population of 1,000 members was generated using random numbers. A random sample of $1,000 P$ was drawn. A second normal distributed population of $1,000 P$ members was generated with a mean of $P^{\prime}$ times the original mean and a standard deviation of $P^{\prime}$ times the original standard deviation. Each member of the random sample was reduced by an amount equal to a random member of the second population. The altered members of the random sample were combined with the unaltered members of the original population to form the modified population. Ten random samples of 100 each were drawn from the modified population and each was compared with the original population using the chi square test. Both $P$ and $P^{\prime}$ were varied from 0.1 to 0.5 in steps of 0.1 . The entire simulation was repeated holding everything constant but using a standard deviation, for the original population, of 20 mph .

TABLE D-1
RESULTS OF HYPOTHESIS TESTING
Hypothesis: $f(x)=h(x)$

| $\sigma=10 \mathrm{MPH}$ |  |  |  | $\sigma=20 \mathrm{MPH}$ |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\boldsymbol{P}$ | $P^{\prime}$ | AI 0.05 LEVEL |  | $P$ | $P^{\prime}$ | AT 0.05 <br> LEVEL |  |
|  |  |  |  |  |  |  |  |
|  |  | ACCEPT | REJECT |  |  | ACCEPT | REJECT |
| 0.1 | 0.1 | 10 | 0 | 0.1 | 0.1 | 9 | 1 |
|  | 0.2 | 9 | 1 |  | 0.2 | 9 | 1 |
|  | 0.3 | 4 | 6 |  | 0.3 | 9 | 1 |
|  | 0.4 | 5 | 5 |  | 0.4 | 9 | 1 |
|  | 0.5 | 4 | 6 |  | 0.5 | 8 | 2 |
| 0.2 | 0.1 | 10 | 0 | 0.2 | 0.1 | 10 | 0 |
|  | 0.2 | 6 | 4 |  | 0.2 | 10 | 0 |
|  | 0.3 | 3 | 7 |  | 0.3 | 7 | 3 |
|  | 0.4 | 0 | 10 |  | 0.4 | 7 | 3 |
|  | 0.5 | 0 | 10 |  | 0.5 | 7 | 3 |
| 0.3 | 0.1 | 8 | 2 | 0.3 | 0.1 | 10 | 0 |
|  | 0.2 | 2 | 8 |  | 0.2 | 9 | 1 |
|  | 0.3 | 0 | 10 |  | 0.3 | 5 | 5 |
|  | 0.4 | 0 | 10 |  | 0.4 | 4 | 6 |
|  | 0.5 | 0 | 10 |  | 0.5 | 2 | 8 |
| 0.4 | 0.1 | 7 | 3 | 0.4 | 0.1 | 9 | 1 |
|  | 0.2 | 1 | 9 |  | 0.2 | 5 | 5 |
|  | 0.3 | 0 | 10 |  | 0.3 | 4 | 6 |
|  | 0.4 | 0 | 10 |  | 0.4 | 1 | 9 |
|  | 0.5 | 0 | 10 |  | 0.5 | 0 | 10 |
| 0.5 | 0.1 | 4 | 6 | 0.5 | 0.1 | 9 | 1 |
|  | 0.2 | 0 | 10 |  | 0.2 | 6 | 4 |
|  | 0.3 | 0 | 10 |  | 0.3 | 2 | 8 |
|  | 0.4 | 0 | 10 |  | 0.4 | 0 | 10 |
|  | 0.5 | 0 | 10 |  | 0.5 | 0 | 10 |

## RESULTS OF SIMULATION

Table D-1 gives the results of the simulation at a significance level of 0.05 . Due to the method used to generate the random populations, which truncated the tails of the distribution, there were slight differences in the number, mean, and standard deviation. Actual values were used in all computations.

The hypothesis being tested is

$$
\begin{equation*}
f(x)=h(x) \tag{D-1}
\end{equation*}
$$

For a standard deviation of 10 mph the hypothesis can be rejected two times out of three only for those cases where $P$ (proportion of the population changing parameter) is 0.2 or greater and $P^{\prime}$ (proportion of mean of change to mean of original population) is 0.2 or higher.

For a standard deviation of 20 mph the only cases that could be rejected two times out of three were those where $P^{\prime}$ was 0.5 and $P$ was greater than $0.2, P^{\prime}$ was 0.4 and $P$ was greater than 0.3 , and $P^{\prime}$ was 0.3 or $P$ was 0.5 .
For the initial values chosen, which are believed to be representative for the parameter "spot speed," it can thus be seen that changes must be of a gross nature to be detectable.

## RESULTS

Most problems associated with highway information systems, except vigilance, occur in arcas of high information challenge-that is, urban or suburban freeways and major arterials. On the other hand, it is on these parts of the highway systems that a large proportion of repeat and familiar users are found. The results of this simulation indicate that sample measurements of a parameter may indicate "confusion" on the part of a certain proportion of the traffic stream if the confusion effect is so large as to cause a major change in the parameter being measured (such as a 25 percent reduction in spot speed), or if the affected portion of the traffic stream amounts to 25 percent or more. Furthermore, as the distribution of the selected parameter becomes more spread (larger standard deviation) the applicability of the method becomes smaller.

It should also be pointed out that this method, as simulated previously, assumes that a steady-state distribution of the selected parameter can be established and that departures from this steady state can be attributed to a single cause. It was assumed that all drivers confused by a certain information source, or by lack of information, would reduce their speed. Situations probably exist where for every confused driver there is an equivalent repeat or familiar driver who will use the same stimulus, or another stimulus at the same location, to reduce his uncertainty and therefore increase his speed. In this case there obviously would be no detectable shift in this distribution.

It thus appears unlikely that sampling of one of the common parameters of the traffic stream can be used to detect confused drivers unless a specific parameter is identified that has a narrow distribution (small standard deviation), for which a steady-state distribution can be established and which is insensitive to factors other than driver confusion.

## REFERENCES

D-1. Quenault, S. W., "Development of the Method of Systematic Observation of Driver Behavior." Report $L R$ 213, Road Research Laboratory (1968).<br>D-2. Roth, W. J., Final Report—Interchange Ramp Color Delineation and Marking Study. Dept. of State Highways, State of Mich. (1969).<br>D-3. Anderson, J. W., and Pederson, V. L., The Effect of Color in Guidance of Traffic at Interchanges. Minn. Highway Dept.<br>D-4. Color Coded Interchange Ramps. Oregon State Highway Dept. (1966).

D-5. Taylor, W. C., and Hubbell, J. C., "The Evaluation of Pavement Marking to Designate Direction of Travel and Degree of Safety." Hwy. Res. Record No. 221 (1968) pp. 23-40.
D-6. Perkins, S. R., and Harris, J. I., "Traffic Conflict Characteristics-Accident Potential at Intersections." Hwy. Res. Record No. 225 (1968) pp. 35-43.
D-7. Perkins, S. R., "GMR Traffic Conflicts TechniqueProcedures Manual." Research Publ. GMR-895 General Motors Corp., Warren, Mich. (1969).
D-8. Voorhees, Alan M., and Associates, Freeway Signing, Concepts and Criteria. McLean, Va. (1966).

## APPENDIX E

## ON THE SATISFACTION OF MACROPERFORMANCE INFORMATION NEEDS *

The driving task analysis, discussed in Part I of this report, shows that macroperformance decisions are at the highest cognitive level and that the information needed at this level is primarily verbal or symbolic. Information needs at this level are lowest on the primacy scale. The more complex a message is, the more difficult it is to transmit. Verbal messages can be transmitted by signs. Because information needs higher on the primacy scale should be met first, and because increased efficiency of transmission, by the use of a different channel, would have a higher payoff at these higher primacy levels, it appears advisable to determine to what extent macroperformance information needs can be met by transmitting them via fixed signs. If macroperformance needs can be satisfied adequately on the visual channel, initial allocation of alternative means of information transmission, which require allocation of scarce resources, can be assigned to higher primacy needs.

Most macroperformance information needs can be characterized as representing answers to the following requirements:

Primary:

1. Define location of driver.
2. Define direction of travel.
3. Relate 1 and 2 to desired route.

Secondary:
4. Indicate alternate routes to destination.
5. Indicate alternate destinations (including services) that can be reached from 1.
6. Indicate how information in 3,4 , and 5 can be obtained in more detail.

In this listing, directional and service information are combined by considering services as alternate destinations.

[^39]Service information is therefore included in a definition of directional information, which includes all information, however derived, necessary to find a given route of specified characteristics, from a given origin to a given destination.

## TRIP DESCRIPTION

The totality of all directional information used by a driver during a trip is a description of the trip from his origin to his destination. Before it is decided how this information is to be presented to the driver, and to what degree this information need is to be aided en route, it is important to realize that there are two basic and different, although overlapping, ways to describe a given trip; one of these must be emphasized in any information system.

A trip description can be either goal oriented or route oriented. In the goal-oriented case, the basic elements of the trip description are the origin and destination. In the route-oriented case, the basic elements are the highway links and the nodes used for making the trip. Thus, a given trip could be described as a trip from Scranton to Cleveland (goal oriented) or as a trip via US 22 and the Pennsylvania and Ohio Turnpikes (route oriented).

In the goal-oriented case (Fig. E-1), the trip plan may consist of nothing more than "Go to Cleveland," or, if more detailed, "Go to Allentown, then to Harrisburg, then to Pittsburgh, then to Cleveland." In the routeoriented case (Fig. E-2), the trip plan would consist of "Go south on the Pennsylvania Turnpike Extension, then west on US 22, west on the Pennsylvania Turnpike, then west on the Ohio Toll Road." The more detailed trip plan, for this case, might read, "Go south for 76 miles on the Pennsylvania Turnpike Extension, then go west for


Figure E-1. Goal-oriented trip plan.


Figure E-2. Route-oriented trip plan.

82 miles on US 22, west for 23 miles on the Pennsylvania Turnpike, and west 62 miles on the Ohio Turnpike."

The various individual drivers approaching any single decision point on the highway will be engaged in a great number of different trips with different origins, different destinations, and different premises delineating the "propriety" of the route. Whichever type of directional information is presented must satisfy the needs of every driver, and, therefore, must be usable for any possible trip. This includes trips to any possible destination, because any set of premises can be selected to decide on a route (scenic, fast, flat, least traffic) and because any point can be an origin.

Although all drivers approaching a given point may have different origins and destinations and may have planned their trips according to different premises, they do have one thing in common-they are traveling on the same highway link in the same direction. A trip description based on destination thus accentuates the differences in the individual trips; a trip description based on route links accentuates the similarities.

It is evident that the information presented on the approach to any decision point cannot be used to lead the driver to a potential destination in a system of goaloriented trip planning because this would logically entail the mention of every potential destination or place at every decision point.* It is thus necessary for the driver to plan his trip in more detail. This will require a sequential listing of intermediate destinations culminating in the ultimate destination. In this case, the information presented to the driver on the approach to a decision point must include all possible intermediate destinations. Although, for any one location, this decreases the amount of infor-

[^40]mation to be given, it still leaves more information than can be transmitted by any non-automated, non-demand system unless each trip planner is required to choose all applicable intermediate destinations from an official, approved list, and this list is detailed enough so that any possible trip through the point must go through one of not more than three possible intermediate destinations.

At any decision point there is, by definition, a minimum of two possible destinations. In the great majority of cases (the intersection or interchange of two or more bidirectional highways) there will be a minimum of three destinations; that is, one destination for each possible direction of travel. If one destination only can be shown for each direction of travel, and if this destination must fit into the trip plan for every possible trip that incorporates travel on this particular highway section in the direction being signed for, this destination must be the next node (junction or intersection) in the direction of travel. Any other choice would not serve drivers whose trip plan calls for a change of direction at this next node. An intermediate destination type of trip plan, therefore, must consist of a sequential list of every node passed on the trip.

It may be argued that this represents an extreme case and that all that would normally be required is a sequential listing of those nodes at which a positive and deliberate change in route or direction is required. However, this argument ignores two important aspects. One of these is the fact that there are many instances in which highway alignment, by itself, is inadequate to indicate the continuing, as against the diverging, direction. Major bifurcations and complex directional interchanges are examples of this. The other aspect to be considered is feedback. A trip plan that consists only of a partial list of intermediate destinations cannot be used as a validity check. The passing of a node point not on the list may mean that no positive action is required at this point. But, it may also mean that an error has been made, either in the construction of the trip plan or in its implementation, and that the driver may have departed from his proper route.

It is possible for a motorist to choose intermediate destinations in constructing his trip plan that are not on the actual route that he intends to take. His trip plan in this case would be in terms of "drive toward A" instead of "drive to A." In this type of trip plan, the necessity of listing every node would no longer apply, because the motorist would proceed toward one intermediate destination either until that destination is reached or until he receives information to depart from this route to take another route leading toward a subsequent intermediate destination contained in his trip plan. In this kind of trip planning, a relatively small number of intermediate destinations can be used to describe a large number of different trips, and it may be possible to develop a great many different trip plans, each of which contains only a relatively small number of intermediate destinations, while staying within the limitation of the number of intermediate destinations that may physically be displayed.

On closer analysis, although this type of trip plan uses destinations as the descriptive elements, it is no longer a goal-oriented trip plan as defined previously. The inter-
mediate destinations used have lost their character of being "destinations" and have become route describers. The "Road to A" becomes just another coding system for describing a route, functionally no different from "US 17" or "Millard Fillmore Memorial Parkway."

A route-oriented trip plan will consist of a sequential listing of all route segments used during the trip. The number of items it contains must, mathematically, be less than the total number of nodes passed on the trip, unless there is a change in route designation between nodes. In practice, there will be a relatively small number of items, because only a small percentage of all nodes passed during the trip will involve changes of route. To cite an example, a trip from Stamford, Conn., to New London, Conn., a distance of 93 miles, involves one route (I-95) but passes 70 nodes (interchanges). The average spacing of interchanges on the Interstate system will be approximately 3 miles, whereas the longest trip on any one Interstate highway, after completion of the system, will be in excess of 3,000 miles (I-90 from Boston to Seattle).

## DIRECTIONAL INFORMATION NEEDS

To implement a route-oriented trip plan, the driver must be able to match potential highway links with the desired ones. He will therefore require information concerning the link he is on (designation of route and direction of travel). At each decision point, he will also require this same information about any other route he could take. These information requirements will be identical for all drivers passing a given point, independent of origin, destination, or premises controlling the choice of route. For the standard case of the intersection or interchange of two bidirectional routes, this involves the description of three highway links, by designation and direction, together with an "action message."

The term "action message" is used here to include all the information required by the driver to place his vehicle on the proper link after this link has been selected as proper from among all possible alternates. It includes such elements as arrows and verbal descriptions, right or left, that denote a path, as well as, in the case of advance signing, information on the distance to the divergence or junction point and mandatory or recommended lane assignment. The action message thus satisfies the situational needs of macroperformance and structures the driver's expectancies in this regard.

Without considering factors of possible descriptive systems, redundancy, repetition, or attenuation, it can be seen that this information requirement can be met by displaying or transmitting four message units (the designation of the three potential links and the action message). This falls within the limitations of the sign channel. This channel can, therefore, continue to be used as the principal means of transmitting this type of information.

With this principle established, its implementation depends on answers to the following questions:

1. How will a route be described?
2. How will a direction of travel be described?
3. How will an action message be given?
4. How will these elements be arranged?
5. Where will the information be given?
6. How often will the information be repeated?

The first three questions deal with the "language" in which the transmitter of information (the traffic engineer) communicates with the receiver of information (the driver). Questions 4 through 6 include, by implication, all of the factors applying to signs as transmitters of information discussed elsewhere in this report. If questions 1 through 3 are described as dealing with the "language" of the communication, then questions 4 through 6 can be described as dealing with the "efficiency" of the communication.

## Route Description

Man has developed many different systems of identification for roads, from the first beaten paths of prehistory to the present Interstate system. However, the identification of these many systems can be reduced to three major categories: (1) by some meaningful name, (2) by an arbitrary designation such as a letter or number, or (3) in terms of its termini.

At present, all three systems exist, with many roads having more than one designation. For instance, within one 5-mile stretch of the Long Island Expressway, alternately designated as NY 495, are found interchanges with the Seaford-Oyster Bay Expressway (NY 135), the Northern State Parkway, and NY 110.

Terminal designations probably came first, reflecting the pragmatic attitude that the importance of a road lay in the fact that it could be used to go to a certain place. The Boston Post Road and the Oregon Trail are examples of this type of designation in American history. Designation by names not related to the terminals of the road probably started by using the name of the authority responsible for the road; "National Pike" and "El Camino Real" are early examples of this type of nomenclature. It is interesting to note that double naming was prevalent even at this early stage. The "National Pike," which started in Cumberland, Md., was also known as the "Cumberland Pike."

Arbitrary nomenclature systems are a relatively recent development reflecting the need for a workable administrative tool in the large-scale administration of highway systems and the allocation and control of construction and maintenance funds. The Interstate, US, and state numbered systems are well-known as are, in certain sections of the United States, nomenclature systems for local roads which may run into four-digit figures (Texas) or twoletter designations (Wisconsin). Frequently, especially insofar as US and state numbered systems are concerned, the designations used administratively do not always correspond to the numbers displayed to the motorist, and the FAP or FAS numbers of given highway sections may bear no relation to the route numbers.

It is open to question, and beyond the limits of this report, whether any effort aimed at standardizing these nomenclature systems is worthwhile. The many arguments in favor of the exclusive use of a basically arbitrary system, route numbers, are well known. [See, for instance, the
discussion of this subject in the Kassel (E-1) survey of California signing practices.] Experience has shown that this system has not found full acceptance by the driving population. Whether this lack of acceptance is a basic fault of the system or a fault of the method of implementation (especially the lack of any meaningful and farreaching public education and information campaign), or consistency of implementation, has not been determined. The difficulty of redesignating routes, and obtaining public acceptance of the new designation, has been demonstrated in many cases.

However, especially in view of the advisability of redundancy in the presentation of information discussed previously, this decision does not have to be made. The partial popular acceptance of route numbers, the undisputed advantages of this system, and the fact that this system is the one that lends itself most easily to computer coding and routing are sufficient reasons to retain it. On the other hand, local, meaningful names that have achieved popular acceptance cannot be eradicated, especially as these names will continue to be used for all non-highway description purposes.

It is therefore recommended that a route be described by both its numerical designation, if it has one, and by a local, meaningful name. This does not mean that there should be no changes in the present nomenclature systems. Inconsistencies and ambiguities that have arisen must be eliminated. At least five numerical systems now coexist (Interstate, US, state, county, and city streets), to which must be added interchange numbering and mileposting. The highway user cannot be expected to absorb the information that US 45 and State Route 50, running concurrently along 40th Street, interchange with I-55, at exit 35, which falls near milepost 30 . (Although this example is, admittedly, fanciful and exaggerated, it should be pointed out that every individual designation used does exist within the Chicago metropolitan area.)

Similarly, a critical look must be taken at local names before the decision to use those names in signing is made. This is especially true where there is a choice of more than one possible name, such as new facilities or facilities known by more than one name, only one of which can be used in the signing. The selection of a class of names, the opportunity for which may arise in "New Town" design, or of individual names, must be based on the following criteria:

1. Ambiguity-Is the designation chosen unique and distinct and easy to distinguish from other names? Does it imply, or could it be interpreted as implying, attributes (such as direction, and road characteristics) that the road does not have? (for example, "Main Street," which does not lead to the central business district; "Washington Avenue," which does not lead to Washington).
2. Memory-Does the designation chosen fall within the memory span of the highway user? Is it easy to remember and recognize?
3. Relatability-Can the designation chosen be related to direction, destination, or topographical features of the route, or to the area in which it is located?
4. Adequacy-If a class of designations is to be selected, does it have enough members to take care of all present and foreseeable future needs?
5. Appearance-Does the designation lend itself to an easily understood visual display without being unduly demanding of sign space?

Whether entirely new facilities should receive names in addition to numerical route designations remains open to question. One possibility would be the use of numerically designated names such as " 605 Freeway" as used in California. From a practical consideration, it appears advisable to assign names in accordance with the foregoing criteria in preference to having these assigned by "vox populi" or by political bodies with other than highwaydirected primary concerns. This, of course, holds true only for urban and suburban facilities. The use of numerical designations for rural roads is so well-established and accepted, being used even for post-office use, that no problems should be encountered.

## Direction Designation

There are a number of possible methods to denote direction. Three of the more prevalent ones may be characterized as common reference, compass reference, and map reference. Common reference direction designations use such common terms as up, down, right, left, and clockwise. Compass reference direction designations use some variations on the compass rose, ranging in complexity from the four cardinal directions to compass bearings given to the nearest degree. Finally, map reference direction designations use some geographically determined location and are of the "to . . ." type. Currently, all three types of designation are used interchangeably, explicitly in some cases and implicitly in others, such as the use of destination on directional signing.

Compass directions obviously represent the most universally applicable system because they can be used to denote almost any possible direction or configuration.* They have the further advantage of being an integral part of existing sign messages. Difficulties are met, however, in those cases where a compass direction is an integral part of the name of a route and the true compass direction, to be used in signing, is at variance with this. For instance, an existing expressway exit, in Illinois, is presently signed "EAST-Northwest Highway." ** A current proposal to replace EAST with EASTBOUND might alleviate this difficulty. There exists no definite body of knowledge delineating the driving public's actual understanding of compass directions, and its ability to use this type of directional designation in route planning and following, especially insofar as compass points other than the four cardinal directions are concerned.

Most common reference direction designators (right, left, straight up, down, etc.) suffer from the fundamental defect that they are subjective; that is, they have no abso-

[^41]lute meaning of their own but their meaning is defined only in terms of the driver's instantaneous position and direction. Trip planning using such a system would prove to be extremely difficult and would require an extremely high degree of ability in spatial perception. Furthermore, this type of designation has, traditionally, been reserved for information on the situational level and should continue to be reserved for that purpose.

Map reference direction designations are in extensive use, either by themselves or, more commonly, supplementing compass directions. This type of designation works only as long as the map reference used is the final or intermediate destination of the driver, or the driver knows the geographic relationship between the map reference and his final or intermediate destination. In a system relying on map references to denote direction, the driver, when preparing his trip plan, is placed in the position of trying to outguess the sign designer so that he can anticipate the cues that he will receive en route. Map references, however, are valuable as redundant sources of directional information, especially when some ambiguity exists as to the "real" direction of the intersecting route (curvilinear routes or highway grids not oriented to the cardinal directions).

The foregoing argument, obviously, does not hold in the case of signing for intersecting routes whose major or only purpose is to serve as a feeder to a single major traffic generator. Airport lead-in roads are prime examples of this, and there is no reason that the name of such a major destination should not continue to serve as a designation of both the intersecting route and its direction.

A different approach to eliminate the necessity of guessing is in effect in some European countries where the list of "official" destination designations is published as part of administrative regulations [Germany (E-2)] or as part of a sign manual [England (E-3)]. It is doubtful, however, whether such a method would be feasible in larger and less densely settled countries.

It can thus be seen that none of the three systems mentioned presents an absolutely clear-cut case for either adoption or rejection. In view of the restricted alphabet available in the common reference system and the need to use this system for the presentation of information on the situational level, and in view of the difficulty encountered in using a map reference system for pretrip planning, it is recommended that primary reliance for directional designations should be placed on compass directions.

Of course this decision introduces certain problems or, to be more exact, perpetuates certain existing problems. The problem of levels of skill in understanding and using this system is mentioned elsewhere. This is discussed at greater length in the section of Part $I$ of this report dealing with a priori knowledge. The problem of ambiguous directions also is indicated elsewhere. This can be overcome by making arbitrary decisions in each case to overcome ambiguity and finding a clear and unequivocal method to communicate these decisions to the driver.

## Point Location-Problem

Route and direction descriptions, discussed in the previous paragraphs, can be considered as defining a coordinate, or grid, system. They are sufficient to answer the question, "Which way am I going?" However, to answer the question, "Where am I?," another element is required. This element consists of a clear, consistent, and unequivocal method of defining points along the route. A clear method of defining individual points on the highway system is of utmost importance to the highway operating agencies, touching all facets of operation, maintenance, emergency services, and cost accounting. Furthermore, to reduce the physical requirements for information transmission to a minimum, a system should be adopted that can be used by both the driver and the highway operating agency.

A study by the Insurance Institute for Highway Safety $(E-4)$ concluded that, "For maximum general public usefulness, as well as for continuous surveillance of traffic by official agencies, the physical existence of some standardized mile posting on the roadside seems unavoidable." A mileage marker system has the advantage of being easily understood, having a natural relationship to the physical features of the highway system, being useful and usable for pretrip planning, and being directly related to the odometer installed in every vehicle. The system currently in use, however, also has several disadvantages. In this system, as applied to Interstate highways, mileages are assigned on a statewide basis, with the zero marker being at the south or west state line, or at the beginning of a route if it starts within the state, with mileage figures increasing in a northerly or easterly direction.

Three distinct difficulties arise. The first of these is that 50 percent of all trips will be made in the direction of decreasing mileage numbers. The second difficulty arises from the fact that a change of reference is encountered every time a state line is crossed. Finally, it is extremely difficult to apply this system to beltways and to loop, spur, or connecting routes. These three factors, although detracting only slightly from the ability of the system to denote unequivocally the location of a vehicle within the highway system, do seriously impair the usefulness of the system in pretrip planning and in checking adherence to and progress along the planned trip.

## Point Location-Recommended Method

The current system need only be modified to minimize the difficulties that now exist. Basically, the recommended system consists of initiating mileposting for each roadway,* independently and independent of state lines. Under this proposal I-90, for instance, would have mileposting ascending from 0 in Boston to 3,000 in Seattle for the westbound roadway and ascending from 0 in Seattle to 3,000 in Boston for the eastbound roadway. Each trip would then be taken in the direction of ascending mileage numbers, and the travel on each highway link would be from one mileage point to another, on the same scale, with the distance traveled along that link represented by the

[^42]arithmetic difference between the entering and departing mileage figures.

Although this proposal eliminates two of the objections listed previously, and is well-adapted to long rural stretches, it does not fully solve all the problems encountered in metropolitan areas. Four highway configurations must be defined and considered separately.

## Spurs (Fig. E-3)

Spurs are highway links that depart from an Interstate route and do not rejoin the Interstate system. It is suggested that, in the departing direction, the mileage numbers continue the main-line numbering system. In the joining direction, the initial point should be assigned a numerical value so that, with increasing milepost values in the direction of travel, the mileage figure for the spur, at the point where it rejoins the main line, is identical with the mileage figure for the predominant direction of travel for drivers entering the main line from the spur.

## Connecting Roads (Fig. E-4)

Connecting roads are roads that connect two different Interstate routes. If a predominant direction of travel can be established, a mileage system that continues the main-line system in each direction can be established and the connecting road can be treated as two unidirectional spurs. If, however, there is no predominant direction of travel (i.e., drivers entering either main-line route are equally liable to proceed in either direction), the optimum solution appears to be to treat the connecting route as a separate and distinct part of the Interstate system, with mileage figures starting at 0 at each end, as described previously for major continuous routes.

## Belt Roads (Fig. E-5)

A belt road is a circumferential highway that forms a closed circle and, therefore, has no assignable predomi-
nant direction or starting point. The belt road usually intersects two or more main-line Interstate routes. If mileage figures are posted in ascending order in the direction of travel, the lack of true direction becomes immaterial and the only problem becomes the selection of a zero point. In most cases, this will have to be an arbitrary decision. There is nothing wrong with making arbitrary decisions as long as they are consistent, predictable, and reasonable. One such suggestion is to designate the free-way-to-freeway interchange lying closest to true north from the city center as the zero point.

## Loops (Fig.E-6)

A loop departs from an Interstate road and then rejoins the same road. Bypasses and business routes are examples of this. Insofar as mileposting is concerned, this alignment presents the most difficulty. This type of road is functionally akin to the connecting road described previously, except that it rejoins the main-line route. However, the system of mileposting detailed for that case cannot be applied here without creating a discontinuity at one junction, unless the loop is identical in length to the intercepted portion of the main route. It could, of course, be treated in the same manner as the connecting road without predominant traffic patterns. However, as shown, this would entail a loss of its coded designation as a loop.

In most cases where loops are constructed, either the loup of the main linc passes through or near the CBD while the other route bypasses it. If the bypassing route is always designated as the main route and the route to the CBD as the loop, it is obvious that there will be little demand for trips using the entire length of the loop. It therefore becomes feasible to break the loop, symbolically, at its closest approach to the CBD, and treat the two halves as spurs in the same manner as previously discussed, thereby retaining both the special designation of a loop and the maximum possible consistency of mileage figures.


Figure E-3. Mileposting system-spurs.


Figure E-4. Mileposting system-connecting roads.

Summarizing these four cases (the discussion could have been extended to others such as spurs and loops crossing more than one other route), they can be treated in one of two ways: (1) as spurs with continuous mileage designations, or (2) as separate routes with independent mileage destinations. The individual decisions as to which method to adopt, where either method is possible, will depend on prevailing traffic patterns and other local conditions.

Special loop and spur designations (e.g., a three-digit number with the first digit representing the character of the route and the last two digits representing the connecting main-line route) should be reserved for highway links


Figure E-5. Mileposting system—belt road.
with mileage indications connecting to the main line. Highway links with mileage designations treated as independent and separate routes should also carry a designation to that effect. Possibly a new type of designation could be developed for this class of urban feeders and distributors.

## PRESENTATION OF DIRECTIONAL INFORMATION

The elements necessary to place a vehicle within the highway system, route direction, and location along route are defined and discussed in previous sections. The next subject to be discussed is how, when, and how often this information is to be given to the driver. In this connection, it must be made clear that the driver needs the information for three distinct and separate purposes, as follows:


Figure E-6. Mileposting system-loop.

1. Pretrip planning.
2. Trip plan following (direction finding).
3. Trip plan validation (orientation).

The first of these points is discussed elsewhere and is not considered here except to emphasize that the information used by the driver in planning his trip must correspond, in form and content, to the information he receives en route.

Direction finding, as commonly understood to mean finding the way to a given defined destination, cannot be universally accomplished by means of information received en route in an information system attempting to satisfy the needs of all drivers at all times. The most that can be expected from an information system is a clear indication of the designation and direction of all possible alternate routes at any decision point which, when compared with a sequential list of road links making up the trip plan, would be sufficient to select the proper path to any destination.

A hypothetical trip plan will consist of a sequential list of route links defined by designation and direction which may include the length of each link (this could be in terms of gross qualitative terms, actual mileage, or driving time). It probably will not include, at least in the case of first-time trips, any information on how to transfer, physically, from one link to the next; that is, the micro and situational implementation of the macro need.

The directional information system, insofar as route following and orientation are concerned, must inform the driver of:

1. The designation and direction of the link on which he is traveling.
2. His location along that link.
3. The designation and direction of all links to which he could transfer.
4. The driving maneuvers required to accomplish each transfer.

Items 1 and 2 represent the orientation portion of the system and are accomplished by displaying route, designation, direction (except in the case of circumferential routes), and mileposts. The frequency with which this information should be given depends on such human factors as short-term memory, processing load, vigilance, and others that vary from one location to another. Therefore, no strict rule can be made as to spacing, except to state that the spacing should be uniform and probably should not exceed 5 miles (equivalent to a $5-\mathrm{min}$ interval at 60 mph ).

Mileposts, by definition, and to make them usable for operating and administrative purposes of the highway authorities, should be placed every mile. Where link designations are given, they should coincide with mileposts to take advantage of expectancy factors, minimize signal searching, and reduce the total number of different signs. Link designation should be repeated at every milepost to maximize consistency and minimize the demands placed on short-term memory. However, economic considerations may require a tradeoff in this area, and the route and di-
rection designation can be shown only at every $n$th milepost as long as $n$ does not exceed 5 .

To meet the requirements of item 3 requires the display of the designation and direction of all highway links on which a driver could be depending for the decision he makes. Item 4 requires the display of information previously defined by the term "action message." A driver approaching a decision point and engaged in a route-following task must:

1. Recognize that this is a decision point.
2. Identify all alternate highway links emanating from this point.
3. Determine which of these links is contained in his trip plan.
4. Determine the necessary driving maneuver to place his vehicle on the selected link.

A decision point occurs every time a driver is presented with more than one possible path of action and is forced to choose one alternative. In its simplest aspect, the decision will be between two alternatives: (1) to continue on the same highway link, or (2) to transfer to a different highway link. Every interchange or intersection is thus a decision point for every driver approaching it. Therefore, the recognition that a decision point exists or is approaching follows directly from the information that more than one travel path is possible. Consequently, except for rare cases, item 1 will require no explicit transmission of information.

The information called for under item 2 must be presented to the driver at a point so that the determinations called for by items 3 and 4 can be made in sufficient time to perform the necessary driving maneuver under all expected road and traffic conditions. This driving maneuver consists essentially of adjusting the tracking and speed control performance so as to be at a given point at, or below, a given speed.

Although a considerable amount of published literature exists on certain aspects of weaving and merging, little work has been reported on in the field of lane-changing behavior.

Several variables determine the time and, therefore, the length of roadway required to make these lane changes. Among these are the parameters of the traffic stream, volume, speed, density, the dynamic properties of the vehicle, and the gap acceptance behavior of the driver.

Because dynamic vehicle properties vary throughout the vehicle population and, especially, because gap acceptance is a subjective population variable, no single definite answer is possible; rather, there exists a probability function defining the required length of roadway in terms of these variables. Work now under way at Northwestern University and at the University of California is intended to define this probability function. For at least one of these research efforts, the proper location of advance signs is one of the specific goals.* Pending completion of this research, no specific rules as to the proper placing of advance signing can be given.

[^43]Experience, analysis of pertinent human factors principles, and the influence of additional factors such as attenuation and the possibility of sign blockage * strongly indicate the desirability of presenting this information at least twice in separate locations. The critical sign location, as discussed in the previous paragraph, will be the location of the second (or repeat) sign in the series. The optimum location of the first sign, with reference to the location of the second sign, is a function of short-term memory. Quantitative evaluation of short-term memory is, however, not available in the literature. Pending empirical evaluation, it is recommended that an average distance of 1 mile, in accordance with current practices, be used. This distance should be adjusted if the speed limit varies appreciably from 60 mph .

The information transmitted by the signs will have informed the driver of the possible diverging links at the approaching decision point and of the proper lane to be in to implement a decision to continue or diverge. Theoretically, no information should ever be presented to the driver that might influence a decision on his part, beyond the point where this decision can be implemented safely and conveniently under all conditions. According to this principle, directional information should not be repeated past the safe location. Information presented as to the beginning of the deceleration lane and the location of the exit should be kept on the situational level without designating the diverging links. In the case of single-exit interchanges this is a feasible procedure unless the distance from the decision point, previously determined for the proper location of the main directional sign, exceeds the short-term memory span. In this case, a tradeoff will be required between the need of reinforcing the previously given information and the disadvantages of presenting what may be new information to the driver at a point when he may not be able to use it safely and conveniently.

However, a serious problem is introduced by the fact that a single decision point on the macro level may include plural decision points on the situational level. A decision to diverge from a given highway link at a given interchange is not uniquely determined; it may be possible of implementation in more than one way. Any multiple-exit interchange (a simple cloverleaf) is a case in point. Also included in this discussion, although somewhat different, is the case of closely spaced interchanges or other highway configuration, where the spacing between successive situational decision points is smaller than the exit-to-main-directional-sign distance.

A conflict thus arises between the need to show specific directional information to drivers in the proper lane and the hazard inherent in showing this information to drivers not in the proper lane. There are two basic methods presently available to handle this situation. The first (and preferable) method is to display this information in the normal manner that is visible to a certain extent by all drivers but at the same time making lane changes in response to this information impossible; in other words, construct a physical barrier between the exiting lanes and the through lanes -thus, in effect, creating a collector-distributor road simu-

[^44]lating the single-exit case. Although it is theoretically possible to approximate this condition with regulatory signing and pavement marking, most traffic engineers would agree that a relatively low degree of observance of such a regulation is to be expected. If the method of creating a single exit configuration is used, the beginning of the new collec-tor-distributor road becomes the decision point, and all critical distances for sign placement are measured from that point.

Where physical or other considerations prevent adoption of this expedient, at least in the short run, and vehicles are left free to change lanes, this directional information must be made invisible, and, therefore, unusable to drivers not in the proper lane. It is almost impossible to make a message visible to motorists in one lane and invisible to motorists in adjoining lanes, using present signing techniques. One way of approaching this is by the use of pavement word markings. However, this method is generally recommended only as an auxiliary source of information ( $E-5$ ). It becomes totally unusable under severe weather conditions or in dense traffic where gaps are insufficient to give adequate reading distance. A pavement message, due to the physical configurations of the vehicle, must be at least 50 ft away from the vehicle to be visible and should stay visible for at least $1 \mathrm{sec}(E-6)$. Therefore, a minimum gap of about 1.5 sec is required. This gap has been found, in one study ( $E-7$ ), to occur less than 75 percent of the time under heavy traffic conditions.

A sign can be "seen" but still be "invisible" if, by some coding techniques, its message is made unintelligible to all but a certain class of drivers. For the present discussion, the class of drivers to which the sign applies is defined as consisting of those who have read the main directional sign. Color, shape, or verbal coding for the various distinct exit possibilities may thus be included in this sign message. The subsequent situational decision point signing will use this code. If, as frequently occurs, the two possible diverging highway links represent two directions of the same route, the cardinal direction, used without link designation, would be adequate coding. If different highway links, or more than two links, were involved, a different coding system would have to be used. Color appears to be an obvious choice for this purpose. However, in view of the primary role of color as a coding device denoting class of information, emphasized in a recent report on this subject ( $E-8$ ), and in view of the problem of color blindness, it appears necessary to relegate color, in this connection at least, to the role of a secondary, redundant, coding device and to rely on primary coding of a verbal or symbolic type.

Basically, the requirement is for a consistent and comprehensive system to code all roadways usable by traffic within an interchange or within a group of closely adjacent interchanges. Interchange numbers represent an existing coding system that, in certain areas, has been amplified to cover coding of individual exit roadways.* Because this system has considerable potential, a closer look at the general subject of interchange numbering appears to be indicated.

[^45]The numbering of interchanges, used extensively on toll facilities, is finding an ever-increasing use on the various expressway and freeway systems in the United States. However, there are three distinct areas in which differences exist: (1) the numbering can apply to interchanges or to individual exits, (2) it can be consecutive or on a mileage basis, and (3) it can be applied to every interchange, or some interchanges may be omitted.

In each of these areas, strong cases can be made for almost all alternatives. The interchange numbering system tentatively adopted by AASHO for the Interstate system requires the consecutive numbering of interchanges, with interchanges between different Interstate routes omitted. No numbers can be omitted due to planned future construction except for approved routes with a definite construction commitment.

For the purposes of directional information, orientation, trip planing, and route following, such a system has several disadvantages. The first is shared with all systems that assign numbers on a route basis. A single trip, involving more than one expressway, cannot be retraced in the opposite direction by using the same interchange numbers. The same interchange will have more than one number, and the number displayed will depend on which of two or more expressways is used as the approach.* This introduces an obvious source of potential confusion, especially in view of the great percentage of trips of the "going-return" type.

The only method possible to eliminate this completely is the assignment of interchange numbers on a system-wide basis, with each interchange receiving a unique designation. Such a system is feasible, and considerable work has been done on it (E-9). However, this results in a cumbersome system, requiring a minimum of six digits for the designation of an interchange. Furthermore, in any such system there must be highway links in which there is no easily discernible, logical relationship between adjacent interchanges. This, combined with the fact that these arbitrarily assigned numbers will usually not be relatable to other designations, highway links, and directions used in the trip plan, will make it extremely difficult, if not impossible, to use these numbers for orientation and validity checks on proper adherence to the trip plan.

Therefore, it is preferable to continue with a system of interchange numbers assigned on a highway basis rather than on a system basis. In view of the recommendation that mileage numbers be assigned individually by direction, the system of interchange numbers must be consecutive, and not on a mileage basis, in order to have one number per interchange per route. If there is no relationship between interchange numbers and mileage numbers, there seems to be no reason to continue interchange numbers across state lines, with the consequent cumbersomely large numbers that, on the transcontinental routes, will reach four figures.

On the other hand, there appears to be no valid reason to continue an artificial distinction between the Interstate

[^46]system and the other freeways and expressways, often built to identical or similar design standards, by omitting interchange numbers for Interstate-Interstate interchanges. To reap maximum benefit from an interchange numbering system, the system must be applied to all interchanges. Although no interchange should be omitted,* the omission of numbers becomes necessary because the highway system is. not static and additional links and nodes will be added in the future.

In this respect, the principal question is how far to go into the future. If a new link has been authorized and located, and its construction has been delayed for strictly budgetary or administrative reasons, unquestionably the pertinent number should be omitted for later assignment. However, if it is a question of a given corridor or desire line, that may with varying probability contain an arterial highway at some time in the future, the answer is not obvious. The same situation exists whenever unknown future land-use development may require additional highway connections. These represent an area where tradeoffs are required between the desire to accommodate future connections without disrupting the system and the desire for the least number of initial discontinuities. The requirement for a continuous transportation planning process ** now being implemented will greatly facilitate the determination of locations where numbers have to be reserved for future connections, at least within urban areas. In rural areas no such easy method is available, and a great deal of experience and judgment on the part of the responsible enginecrs will be required. In the densely settled eastern states some workable method undoubtedly will be developed. In some of the most sparsely settled, fast-growing western states (e.g., New Mexico) it is likely that the optimum solution to this problem will consist of a periodic renumbering. This is feasible if it is consistent, expected, and predictable, and if the public information media are enlisted.

If all interchanges are numbered in accordance with the guidelines discussed in the previous paragraphs, it becomes possible to use a suffix to identify the separate roadways within the interchange (the use of a single letter designation for ramps is a standard highway design, construction, and maintenance procedure). Furthermore, this coding system would clearly indicate to the driver whether he is approaching a single- or multiple-exit interchange. The primary reason for this exit coding is to prevent reactions by the driver to information received past the "point of no return." Of course, a welcome by-product of this coding is that it represents a recoding process and therefore places a lesser demand on the sign channel. For this reason, the code should be as arbitrary as possible and not be usable by any driver who does not have the key--that is, any driver who has not read the principal directional sign. Therefore, and in order to use a coding system usable irrespective of the number or ultimate direction of exit roadways, it is rec-

[^47]ommended that the coding consist of the letters in alphabetical order starting with $A$, rather than be a coding system tied to cardinal directions. Color, probably in the form of a background panel for the code letter, may represent a desirable degree of redundancy, especially in the case of complex interchanges, using systems of collection-distribution and connecting roadways, where more than two situational decision points are encountered by the driver while transferring from one link to the next. In effect, then, the route through the interchange leading to a given highway link going in a given direction becomes a subtrip, which can be trailblazed. Care will have to be taken to ensure that all roadways leading to the same link receive the same coding.

The key element in the convenient and safe navigation of the interchange thus becomes the coding system of the individual ramps and the driver's understanding of this system when perceived from the directional signs. This comprehension will be increased if the driver realizes the importance of this information and if his expectancies have been structured to expect this information. For this purpose, an advance directional sign is proposed whose purpose will be to alert the motorist that a macro decision point is approaching and to present him with some warning of the degree of complexity of the situational decisions that will be required. This sign, as shown later, will also serve the secondary purposes of identifying the through direction and, if required, showing some destinations or synonyms for cardinal directions.

It is seen that the recommended signing for a directional decision point consists of an advance directional sign, two main directional signs, and a series of coded situational decision signs. The next subject to be discussed is, logically, the message content and arrangement of these various signs.

Previous analysis shows the necessity of displaying information concerning the designation and direction of all available highway links, together with the action message, on the main directional sign. This would normally include the continuation of the highway link on which the driver is approaching the decision point. However, in the majority of cases, the continuing highway link is clearly indicated by highway alignment elements, and this information need is therefore satisfied by informal aiding reinforced by orientation markers. To conserve sign space and reduce reading time, the continuing direction should be omitted from the main direction sign except where alignment may create uncertainty. The use of overhead signs (discussed later herein) is recommended.

It is more important to show all the information than to repeat some of it for greater comprehension, and, therefore, the action message on the sign should take precedence over redundant route descriptions. The interchange number, with suffixes, represents the coding key for plural-exit interchanges and can be considered part of the action message. In the case of the single-exit interchanges, where such coding is not required, the interchange number becomes redundant route designation information, except insofar as the absence of suffixes indicates to the driver that he is approaching a single-exit interchange. A possible


Figure E-7. Main directional sign—single-exit interchange.
layout for a main directional sign, for a single-exit interchange, is shown in Figure E-7.

Figure E-8 shows a possible layout for a main directional sign for a double-exit interchange. The exit coding is contained in the suffix to the interchange number that, in addition, is recommended to be color-coded as shown. It should be emphasized that these sketches, and all other proposed sign designs in this section, show only one possible approach presenting the needed information. Considerable additional research is required before these designs are finalized.

The advance directional sign is designed to structure the driver's expectancies of the driving task that will be required of him and of the information he will need to accomplish this task. This is done by a schematic representation of the interchange configuration, that will permit him to relate the approaching interchange to his past experience with similar configurations. Figures E-9 and E-10 show suggested designs for this sign for diamond (singleexit) and cloverleaf (double-exit) interchanges. This sign also identifies the through route and gives synonyms for the cardinal directions in the guise of principal destinations.

Schematic or map-type signs have caused considerable discussion in recent years. Many snap judgments, both for and against, have been formed on the basis of what, scientifically, would be considered insufficient empirical evidence and insufficient definition of the variables involved. Even those empirical investigations that have been made (E-10) did not include sufficient variables to give an unequivocal answer. In view of the ability of this type of sign to display information, considered apart from the pos-


Figure E-8. Main directional sign-double-exit interchange.


Figure E-9. Advance directional sign-single-exit interchange.
sible difficulties in receiving and using this information, a wide-ranging, comprehensive, scientific investigation of all possible implications of this type of signing is essential.

Past the location of the main direction sign, at the decision point, no further directional information is given. All other signs contain situational information coded in accordance with the previous discussion. The situational decision points occur at the beginning of the deceleration lane, at the gore of the ramp, and, in the case of complex interchanges, at subsequent exits from or intersections of collector-distributor and connecting roadways. The signing at the beginning of the deceleration lane is fairly simple and obvious. The gore signing, however, raises some questions. Any sign located in the gore is an exposed position and contributes to the severity of accidents involving vehicles leaving the roadway at this point. From the standpoint of highway safety, the elimination of any fixed signing in the gore, and the consequent possibility of using this location as a recovery area, is desirable. The question is whether this can be done while still meeting the information needs of the driver and without introducing uncertainty.

In the case of single-exit interchanges, any driver in the deceleration lane presumably wishes to use the ramp and, therefore, adequate delineation of the gore is all that is required, especially if the deceleration lane is of the continuous taper type ( $E-1 /$ ) which places minimum situational demands on the driver. However, in the case of plural exits, the gore sign becomes more important and is essential where a common deceleration lane serves more than one exit roadway. Color-coded delineations, which have proven effective in similar applications ( $E-12, E-13$ ), can be used in those instances where it is decided that the gore


Figure E-10. Advance directional sign-double-exit interchange.
sign can be omitted, and would also prove beneficial as a redundant source of information, even when the gore sign is crected.

Figures E-11 and E-12 show the proposed arrangement of signing, discussed previously, for one approach to a diamond and cloverleaf interchange, respectively. An extension of the principles and applications already discussed would be used to develop signing for other interchange and ramp configurations. If the interchange configuration requires more precise lane assignment than can be achieved with messages, overhead sign placement must be used. This will also be the case where lateral restrictions or sight distance limitations prevent the use of shoulder mount signs. The message content and arrangement for overhead signs will remain the same, except that the through highway designations and direction should also be shown on the same structure. If lane assignment techniques are used, care must be taken that no lanes remain unassigned and that all possible alternates are clearly identified.

## SUMMARY OF DIRECTIONAL INFORMATION SYSTEM

The type of directional signing proposed complements a previously made trip plan and therefore succeeds only insofar as the trip plan is correct and relatable to the signing. The skills and information required to make such a trip plan are discussed elsewhere in this report. However, there will be times when the trip plan proves inadequate or when the driver, deliberately or inadvertently, departs from it. For the purpose of this discussion, any such occurrence will be considered a termination of the trip. Because the driver has not yet arrived at his ultimate destination, he must prepare a new trip plan to his ultimate destination, using the point on the highway system at which the previous trip terminated as the new origin.

The opportunity and physical facilities to make this new
trip plan can thus be seen to be an integral and indispensable part of the proposed directional information system. These facilities can run the gamut from a widened shoulder, sufficient for a driver to stop and consult a map, to a completely staffed information center with trained person nel ready to assist in trip planning and route selection. The type of facility provided depends on economic considerations balanced against the probability of need, which is a function of average trip length, volume, trip-purpose distribution, and percentage of repeat trips. For any location, apart from strictly urban commuter highways, the minimum requirement is probably a permanently weatherproof, mounted highway map and a telephone. Further sophistication might involve the availability of more detailed tripplanning aids, from direct-line telephone service to such trip-planning agencies as a motor club, up to elaborate electronic devices that, on demand, would display or print out the desired trip plan. The last of these appears to be a natural outgrowth of automatic, demand directional information systems now in the development stage ( $E-14$ ). The map, other information display, and telephone are now provided in Interstate highway rest areas in several states. For instance, Michigan furnishes a weatherproof enclosure in which are displayed the state map, tourist information, and police and emergency phone numbers, in addition to a standard telephone.

These informational rest areas or turnouts would, in turn, become important services to the motorist; their location would be clearly identified, and the route thereto would be easy to find. Some standard method of signing or trailblazing will have to be developed. At these information sites motorist service information would also be found, as recommended in a report on this subject ( $E-15$ ).

## SERVICES AND OTHER MACRO INFORMATION NEEDS

The availability of services, when set against actual or expected needs therefor, is one of the inputs to the trip plan. In the case of predictable needs (such as lodging), service availability may directly influence the choice of an intermediate destination. The need for this information, having been satisfied in the pretrip phase, will no longer exist in transit. IIowever, most service needs are less exactly predictable; even those that are predictable will sometimes occur at times or places other than predicted. However, even if they are not always predictable in the pretrip phase, normal (as opposed to emergency) services are either predictable in the short run (such as the distance a vehicle can travel after the fuel gauge shows empty) or postponable to a certain degree (such as the need for food). If, in accordance with the scheme of analysis followed here, the need for services is considered as the generator of a revised trip plan, then service information is one of the inputs to this revision and the predictability or postponability of these needs allows time to make such a trip plan.

Making a trip plan entails choosing a destination and making a sequential list of the highway links (by designation, direction, and length) that make up the route to this destination. In the trip plan discussed here, the destination will be chosen by the availability of needed services. This will be either the next destination along the old trip plan


Figure E-11. Directional signing-single-exit interchange.
where these services are available or another point, usually also on the old trip plan, expected to be passed by the time the service needs must be satisfied. In most cases, except for long-range planning for major meals and lodgings, the revised destination will be the same highway link (in the same direction) on which the driver was traveling when he revised his trip plan. The link designation and direction will, therefore, already be contained in the old trip plan and the revision will consist of determining the new intermediate destination and the link length intercepted between his current position and the intermediate destination.

Therefore, the information required consists of a listing of approaching intermediate destinations where various services are available * and the distance thereto. A possible

[^48]

Figure E-12. Directional signing-double-exit interchange.
method of presenting this information is shown in Figure E-13. Because the need for normal services is either predictable or postponable, and because the sign, in the form suggested, does not depend on identification with any particular interchange, its spatial location is not critical. Therefore, it can be located at any point on the roadway where analysis shows a relatively low information processing load exists.

It should be emphasized that the suggested sign shown in Figure E-13 is more an indication of required information


Figure E-13. Proposed service information sign.
than a recommended method of displaying this information. It is realized that, from the human factors aspect, the suggested sign contains a great deal of information and, therefore, presents the driver with the necessity of making complex choices between alternates at a level that may be beyond his abilities. This underscores the difficulties inherent in presenting adequate information for, on analysis, it can be seen that the sign contains a minimum of information; namely, the location of the next service facility for each category and the consequence of not using this facility. The necessity of information presentation and processing off-line, in the pretrip phase or during stops along the trip, cannot be overemphasized.

Service needs have been analyzed in the guise of creating alternate destinations. Other factors may have the same result. There exists what may be called a class of "intervening opportunity" destinations. These, applicable mostly to recreational travel, or mixed-purpose travel with a recreational element, consist of attractions unknown at the time of preparing the trip plan (which would have been included if known); attractions that, although known, were omitted because they did not fit into the premises (such as expected travel time) used; and attractions that fall somewhere between these extremes.

Similar in nature are major traffic generators (e.g., airports and stadiums) that are either difficult to relate, from existing maps, to a definite highway approach, or are so well-known and frequented that there is a population expectancy of their being shown on highway directional signs. A third class of information needs includes secondary highway links within the influence of interchanges, that physical limitations do not permit to be shown on the main directional signs.

In view of the desirability of having the decision to use an interchange depend solely on recognizing which interchange it is, and not on an analysis of information describing attributes of the interchange presented at the same time, all information that might affect this decision should be available to the motorist well before the actual interchange signing begins. All the types of information discussed in the preceding paragraphs fall within this category and should, therefore, be presented well in advance of the interchange. With the use of interchange and exit numbers as coding devices, this information should be presented, as in the case of service information, at locations of low information processing load. This type of information is especially adapted to use at locations where some information should be presented for the purpose of raising the driver's level of vigilance.

## CONCLUSIONS

Macro needs are so diverse that they must first be reduced to a common frame of reference before they can be met on a population basis. The various highway links making up the individual trips are suggested as the common denominator. Macro needs, being low on the primacy scale, must yield to micro and situational needs and, therefore, should be satisfied, to the greatest extent possible, in areas of minimum micro and situational demands. The pretrip phase, where only macro needs exist, should, therefore,
be used to the greatest extent possible. In-trip information should be presented between interchanges. Interchange signing should have, as its primary purpose, correlation with the trip plan and should be so designed and located that the situational needs of following a path through the interchange are emphasized.

## REFERENCES

E-1. Kassel, J. T., Review of Signing Policies and Procedures. Div. of Highways. State of Calif.
E-2. Register of Ultimate and Intermediate Destinations on the Federal Autobahn. 1958 ed. The Secretary of Transportation (in German).
E-3. Informatory Signs for Use on All-Purpose Roads. Ministry of Transport, HMSO, London (1964).
E-4. A Summarized Review of Mileposting on State Maintained Highways in the United States. Insurance Institute for Highway Safety, Washington, D.C. (1967).

E-5. Matson, T. M., Smith, W. S., and Hurd, F. W., Traffic Engineering. McGraw-Hill (1955).
E-6. Mitchell, A., and Forbes, T. W., "Design of Sign Letter Sizes." Proc. Amer. Soc. Civil Eng., Vol. 68, No. 1, p. 104 (1942).
E-7. May, A. D., Jr., and Wagner, F. A., Sr., "Headway Characteristics and Interrelationship of Funda-
mental Characteristics of Traffic Flow." Proc. HRB (1960) p. 525.

E-8. Report of the Special Committee on Color. National Joint Committee on Uniform Traffic Control Devices (Jan. 1967).
E-9. Emery, R. H., Grayum, J. Z., and Mammano, F. J., "A Technique of Highway Coding for Route Recognition and Position Description." Hwy. Res. Record No. 186 (1967) pp. 1-8.
E-10 Moore, R. L., and Christie, A. W., "Design of Sign Letter Sizes." Proc. Amer. Soc. Civil Eng., Vol. 68, No. 1, p. 104 (1942).
E-11. Highway Design and Operational Practices Related to Highway Safety. Special AASHO Traffic Safety Committee, Washington, D.C. (1967).
E-12. Interchange Ramp Color Delineation and Marking Study. Mich. State Highway Dept. (June 1965).
E-13. Color Coded Interchange Ramps. Oregon State Highway Dept. (Jan. 1966).
E-14. Hanysz, E. A., Quinn, C. E., Stevens, J. E., and Trabold, W. G., "DAIR-A New Concept in Highway Communications for Added Safety and Driving Convenience." Research Publ. GMR-600, Research Lab., General Motors Corp. (1966).
E-15. Kuprijanow, A., Rosenzweig, S., and Warskow, M. A., "Motorists' Needs and Services on Interstate Highways." NCHRP Report 64 (1969) 88 pp.

## APPENDIX F

## SURVEY OF POSSIBLE AIDING TECHNIQUES *

## MEANS OF TRANSMISSION OF INFORMATION BY INFORMATION DISPLAYS OTHER THAN SIGNSPRINCIPLES AND TECHNIQUES

The elements of a communication system, and a discussion of these elements in terms of signs, appear in Part I. Signs represent a communication system that can be characterized as one using visual reception and fixed-message, fixedposition information displays exterior to the vehicle. As such, the sign system is found, by the task analysis, to be the most widely used information scheme for the formal aiding of situational and macroperformance information needs.

However, the analysis of the driving task and the "Inventory of Information Needs" (Tables 3 through 10) show that there are certain classes of information needs that cannot be aided by signing (characterized in that the information satisfying the need is not fixed), and there are certain

[^49]classes of information needs for which signs are not the optimum means of aiding. Furthermore, signs are subject to a loss of effectiveness under certain attenuating (noise) conditions.

For this reason, a survey of other formal aiding techniques was undertaken. This appendix discusses techniques for the presentation of information by means other than signs.

These techniques are presented in terms of the specific information needs to which they could apply. However, for purposes of this discussion, the aiding techniques can be considered in accordance with the following scheme:

1. In-vehicle displays, visually received.
2. In-vehicle displays, received via a sensory channel other than visual.
3. Outside-of-vehicle display, visually received.
4. Outside-of-vehicle display, received via a sensory channel other than visual.

Before these ways of presenting information are considered, there are several general factors that apply in the selection of any one technique.

## General Principles

## Technical Feasibility

Whatever the means of aiding and whatever the information needs aided, the technique itself and every part thereof must be carefully investigated to ensure its being feasible. Although a technique based on a "possible future development" or "breakthrough" may be of academic interest for potential future application, application to the existing highway/vehicle system to solve an existing problem is not feasible.

## Physical Feasibility

Assuming that a technique is shown to be technically feasible, its implementation must be physically possible within the constraints of the vehicle and highway to which it is to be applied. Thus, for example, it may be possible to build a piece of equipment to do a particular task; however, if the equipment weighs $4,000 \mathrm{lb}$ or fills most of the usable interior space of the vehicle, consideration of such equipment is obviously futile. Physical adaptation to the driver's capabilities also is a requirement fitting into this category; if a technique, although technically and physically feasible, demands excessive muscle power (or unusually keen eyesight) for the driver to use it, its application becomes impractical.

## Economic Feasibility

Assuming that a technique or equipment meets the requirements of technical and physical feasibility, it must be not prohibitive economically to (1) the individual motorist, if an expenditure on his part is involved, and (2) to the state or municipality that will have to bear the burden of acquisition, installation, maintenance, and operation of any roadside or centrally located equipment. A cost/benefit analysis should be made. The inherent difficulty of assigning monetary value to the benefits to be derived will make such an analysis extremely difficult and probably will allow only qualitative or rank order results.

Even if the benefits to society can be evaluated, subjective differences will be introduced on an individual basis. Unless in-vehicle equipment is made mandatory by Government action, the decision to buy will have to be made by the individual driver using individual subjective evaluation of benefits. Even if a given individual assesses these benefits highly, the ultimate decision to buy will depend on the ability to pay and the basic need for transportation.

## Performance

Whichever technique or equipment is chosen, it must be capable of doing the job that needs to be done. This may be considered to be a trivial or self-evident factor; it is stated, however, because it is easy to apply aiding techniques that, although feasible, are but of secondary impor-
tance. For example, aiding an informational need in some particular position on the primacy sale at the possible expense of one higher on the scale, or aiding in a situation where presently there is no aiding at all and the driver does not suffer unduly from the lack of such aiding, either in convenience or safety, might be considered superfluous. The aiding technique, in other words, must fulfill a distinct need, presently not fulfilled, in a manner that is timely and readily usable by the driver.

## Improvement

If a technique or equipment is chosen to supplant or supplement an existing technique of information transmission, reception, and/or presentation to the user (driver), such an application must represent an improvement on the existing means of information presentation in terms of increased probability and greater ease of reception and comprehension, reduced probability of ambiguity, and/or more timely presentation.

## Compatability

As of July 1967, almost 3 million passenger cars and the same number of trucks whose model year anteceded 1953 were registered in the United States. In excess of 16 million motor vehicles were 10 years old or older. A period of 15 years thus seems to be a reasonable figure for a 95 percent turnover in vehicles, and 10 years seems reasonable for an 80 -percent turnover. Even a 50 percent turnover, based on these figures, takes almost 6 years. (These figures are for the period of longest consecutive prosperity in U.S. history. An extended slump or depression would tend to increase the time required by postponing new car purchases.)

If a certain aiding device involving in-vehicle instrumentation is introduced, and assuming that it is automatically installed in every vehicle produced after a certain date, there will be an appreciable extent of time in which instrumented and noninstrumented vehicles, in varying proportion, share the highway (assuming that the device is of a degree of complexity that does not permit extremely easy and cheap after-installation). Any aiding device must thus be able to operate within such a mixed vehicle population, and the safe and convenient operation of a vehicle cannot depend on the particular device being installed in other vehicles. It should be evident that this lack of dependence does not apply only to the electrical and mechanical attributes of the device. Extreme care must be taken so that the drivers of instrumented vehicles do not expect this device to be universal and change their driving patterns in reliance thereon.

## Reliability and Maintainability

Any nonsigning aiding technique may be exclusive-that is, it may be the only method by which information is transmitted, or it may only supplement, as an additional degree of redundancy, the same information being presented by signs or by another means of transmission. Even in the latter case, the nonsign method may be so superior in con-
venience, or attention-getting characteristics, as to become the dominant means of information presentation, with signs becoming redundant.

If the highway user relies mainly on such a method, and changes his driving patterns in accordance (as might be the case with a proximity detector when driving in fog), the reliability of such a device would have to be extremely high. It would have to be in a range usually supplied only in the aviation and manned space flight fields; furthermore, it would have to incorporate a positive "fail-safe" feature. If the device serves only as a display of redundant information, or if the information transmitted ranks low on the primacy scale, a positive "fail" indicator, with high at-tention-getting value, may suffice.

Reliability and maintainability are also important aspects when one is considering any device whose proper operation is essential to the operation of a vehicle. Owing to the prevailing organization of society, down time of a private automobile may, like sickness, approach the dimensions of a family economic catastrophe.

Furthermore, in the discussion of any individual technique, the communication systems elements previously presented apply:

1. There must be a message-this message must be information needed by the highway user, that satisfies the needs of the highway user.
2. The message must be transmitted to the receiver.
3. The receiver must be tuned to the necessary channel.
4. The message must be received and understood.

## In-Vehicle Displays-Visually Presented

When in-vehicle displays visually presented are considered, most of the discussion relative to signs is applicable. The main difference is that "transmitter" and "receiver" involve the possibility of more than one "transmitter" and more than one "receiver." For example, "transmitter" could refer to the transducer sensing whatever is to be displayed (headway detector) or to the induction radio transmitting a signal to the vehicle; "transmitter" could also refer to the specific display, in the vehicle, that the driver looks at. Conversely, "receiver" could refer to each of these devices, in that it receives a signal. In the ensuing discussion, transmitter and receiver, unless specifically noted otherwise, refer to the display in the vehicle and the driver, respectively. With these distinctions in mind, it can be seen that the previous discussion concerning the following factors applies:

1. Comprehension.
2. Emphasis.
3. Rejectability.
4. Expectancy.
5. Uniformity.
6. Consistency.

A discussion of in-vehicle displays is beyond the scope of this report, but appears in Morgan et al. ( $F-1$ ) and in Woodson and Conover ( $F-2$ ).

Regarding receipt of in-vehicle displays, the important reception characteristics are accommodation (the driver must change focus from his display panel to the external
environment) and visual acuity for near objects (the driver must be able to read displays that are relatively close up). Both are factors in the aged driver. His accommodation slows and his ability to focus on near objects deteriorates (presbyopia), acording to Schmidt and Connolly ( $F-3$ ). Bifocals or trifocals for elderly drivers may be a necessity.

## In-Vehicle Display Presented by Non-Visual Means

The principal in-vehicle displays presented by nonvisual means involve the use of the auditory channel. A discussion of display configurations is beyond the scope of this report; see Morgan et al. ( $F-1$ ) and Woodson and Conover ( $F-2$ ) for complete discussion of auditory displays. Several means of displaying information via in-vehicle auditory displays are discussed later in this appendix. In the use of auditory in-vehicle displays, certain transmission and reception factors must be considered:

1. Transmission Factors:
a. Comprehension-As in the case of visually displayed information, auditory information must be presented so that the driver understands the mes-sage-that is, auditory information must be either in understandable English if the message is verbal,
l or in a code form known to the driver if nonverbal.
b. Emphasis-Some means of emphasizing important messages will be required (warning tones, buzzers, etc.).
c. Repetition-Same as for signs.
2. Reception Factors:
a. Level-The sound level must be sufficiently high to overcome the in-vehicle noise level, estimated by Hulbert ( $F-4$ ) as 90 decibels ( dB ) in heavy traffic.
b. Masking (Signal-to-Noise Ratio) -Masking refers to the effect that unwanted sounds (noise) have on intelligible sounds (signals). The noise has the effect of raising the hearing threshold and decreasing the intelligibility of the signal. Woodson and Conover ( $F-2$ ) consider 65 percent of intelligibility as an acceptable value for verbal stimuli and suggest a signal-to-noise ratio of 5 at 90 dB .

In the presentation of in-vehicle information by the auditory channel, the partially and totally deaf driver, as well as the aged driver who loses tone discrimination at a rapid rate after age 40 , must be considered. Because most states do not require a hearing test, and because it would not be equitable to exclude drivers on the basis of poor hearing, it is suggested that the auditory channel be reserved for supplemental information presentation. This is especially true, because at least one study ( $F-5$ ) indicates that deaf drivers may be under a definite handicap in certain driving situations.

## Outside-of-Vehicle Displays-Visually Presented

The previous discussion relative to signs is applicable for the majority of visually presented verbal and symbolic information. Therefore, with the exception of location and
location-related variables, the discussion is applicable to the use of holography. Regarding location-related variables, the holographic techniques allow for much more freedom of placement of the information displays.

There remain other major classes of outside-of-vehicle displays, visually presented. These are: (1) markings and delineation, (2) traffic signals, (3) variable signs, and (4) miscellaneous.

## Markings and Delineation

Pavement Markings as Information Sources-Knowledge of Codes.-There are codes for pavement markings (edge lines, center lines, lane lines, stop lines, and crosswalk markings) that require some a priori knowledge on the part of the driver.
Pavement Markings as Transmitters of Information-Detectability.-Because pavement markings are always present, and because use of pavement markings on the part of the driver was found to be over-learned and automatic, the problem is not one of missing the markings, provided they are present. The important factor is contrast ratio, although Rockwell and Ernst ( $F-6$ ) found that little brightness is required (therefore, low contrast) at night to detect and follow lane markings.

The problem of noise becomes critical, especially climatological factors such as snow and rain.

Delineators. Delineators are primarily a redundant source of intormation. 'The information need that they satisfy (horizontal alignment) is usually satisfied by informal means, mainly direct perception of the highway and the environment. The delineators take over when ambient lighting conditions prevent this direct perception. These devices must therefore be designed for nighttime use and headlight illumination. It should be pointed out that the value of this device has been questioned. A good survey of various aspects of this problem appears in a report by Dart (F-7).

1. Codes-There is an existing coding system ( $F-8$ ) depending on color and number (or shape) of the delineators. Indications are, however, that knowledge of this coding system is not widespread.
2. Detectability—Delineators appear as point sources of light, and the critical factors in their detection are luminance and brightness at the driver's eye. Research to optimize these factors is continuing; a new type of delineator, for curve applications, is now being tried in Michigan (F-9).
3. Legibility-Legibility is not a factor except insofar as coding by the use of multiple delineators is concerned.
4. Noise-All factors contributing noise to visual transmissions apply. Because, to fulfill their purpose, delineators must be placed close to the roadway, they are particularly prone to accidental damage and to mud splattering.
5. Location-The primary information transmitted by a delineator is its own location. The highway user, by inference based on a priori knowledge, can then satisfy his need for information concerning the location of the pavement edge and future highway alignment. The lateral and longitudinal location of the delineator is thus of prime impor-
tance. The spacing between adjoining delineators is important for continuity of information transmission and may be critical if the spacing itself is coded information.

## Traffic Signals

The broad category of traffic signals, which includes traffic control signals, flashing beacons, and railroad grade crossing control, satisfies a considerable number of motorist information needs. Most of these devices are usually considered to be of a regulatory nature. However, regulatory devices also work by giving the highway user information where the information need to be satisfied can be expressed as "it is legal/safe/permitted to perform a certain driving maneuver."

Traffic Control Signals.-Traffic control signals have received much attention, and a considerable number of studies appear in the literature. Basically, a message is coded by color, symbols (arrows), and position within an array. This message indicates to the driver whether he has the right-of-way over potential conflicting traffic (vehicular or pedestrian) and, therefore, whether it is safe, and lawful, for him to proceed. The elements of color, brightness, symbols, and position within the array have been thoroughly analyzed, and their design ( $F-10$ ) and application ( $F-11$ ) have been standardized.
Because this is basically a visual display, analogous in some respects to signs, most of the previous discussion of signs applies and is not repeated here. Certain factors, however, apply only to signals or assume much greater importance with signals so that a separate discussion is warranted.

1. Color-Any transmission of information that uses color as its primary coding device must undertake to handle the problem of color weakness, which affects about 8 percent of the population in varying degrees. This has been taken into account by shifting traffic-signal green into the blue-green area so as to obtain maximum contrast ( $F-12$ ). The fixed position of each signal indication within the array serves as redundant coding. Proposals have repeatedly been made to add another degree of redundancy by shape coding of the individual lenses. None of these has found acceptance, although one commercial device, embodying this principle, is currently undergoing limited field tests. A comprehensive research effort in this area, to identify a problem if it exists and to develop adequate solutions thereto, is recommended.
2. Size-The nominal 8 -in. traffic signal lens has been a standard for many years. More recently, $12-\mathrm{in}$. lenses have been introduced, requiring a choice in application from the traffic engineer. The $12-\mathrm{in}$. lens has considerably greater attention-getting value and legibility, especially against competing visual need. On the other hand, excessive use of this device might tend to structure the driver's expectancy toward the larger signal lens, with a consequent loss of impact on the part of the 8 -in. lens that continues to be used in the majority of installations. A technical committee of the Institute of Traffic Engineers * is investigating this

[^50]problem, and a draft report, now undergoing final editing, contains recommended application practices.
3. Message-The main difference between traffic control signals and other visual displays, such as signs, is that signals do not display a fixed message but rather one of a number of possible messages. With special turn phasing, provisions for pedestrians, and the use of arrow indications, this number may be considerable; even with the standard three-lens traffic signals, using no overlaps or flashing indications, there is a minimum of three possible messages: red, yellow, and green.

The driver, after detecting the signal, must decide which message is geing displayed. Furthermore, in view of the frequency with which these messages change (a complete signal cycle may take as little as 40 sec ), a new information need is created. The driver must know how soon the message is likely to change. The yellow indication was introducted into the signal cycle as a partial solution to this problem; its appearance indicates that a transition interval is in effect and that a red indication will appear next. That this has not completely eliminated driver uncertainty as to the approaching end of the permissive and safe ("go") period is shown in several studies ( $F-13, F-14$ ). A number of remedial measures have been proposed, ranging from green-yellow or red-yellow overlaps to direct displays of the amount of green time remaining by either a clock-type device or by a countdown digital display superimposed on the traffic signal. Such tests and evaluations of the latter types of devices have been done by distributors of patented devices with a vested interest. This is another area in which a comprehensive research program, identification of the problem, and potential remedial devices are necessary.
4. Uniformity-Because a traffic signal displays a coded message, it cannot satisfy an information need unless the code is known. Furthermore, the code is arbitrary and thus not self-learning. Because the basic code, red-stop, green-Go, yellow-caution, is so well-known, it is essential that no local departures from it be permitted and that no changes in it be made without the most thorough preparation. Permitting certain maneuvers in contradiction to this code by local action will therefore tend to create uncertainty and possible system failure among drivers not familiar with the local code variant.

Flashing Beacons.-Flashing beacons represent a type of traffic control signal where the message does not change and that has its own code. Apart from these differences, the preceding discussion applies. It should also be pointed out that, under certain conditions such as maintenance work or low traffic flow, a regular traffic control signal may be switched to flashing operations-that is, act as a flashing beacon. This can be considered an extension of the problem of changing message and may also introduce a further degree of uncertainty. A driver first perceiving a traffic signal and detecting a yellow indication will not be immediately sure whether this yellow means "red (stop) indication about to appear" (traffic control signal code) or "proceed with caution" (flashing beacon code). Only additional monitoring will resolve this uncertainty, with the
consequence that other potential sources of information may be ignored. Because traffic control equipment is available that minimizes any possible adverse effect of normal signal operation during light traffic conditions, it is recommended that flashing indications of regular traffic signals be employed as little as possible.

Lane Control Signals.-Lane control signals indicate which lanes are open to traffic and which are closed, in cases where unbalanced or reversible lane use has been established. The standard signal indication code consists of a red X for "lane closed," and a green down arrow for "lane open." Thus, both color and shape coding are used. Occasionally, a yellow indication is used to indicate that a lane previously open to traffic is about to be closed.

All the elements previously discussed in conjunction with traffic control signals apply. Because these devices are a relatively recent innovation, additional research is needed on optimum spacing, optical properties of the signal itself, and methods to handle the transition from an uncontrolled to a lane-controlled section of highway. One operational problem is introduced by the fact that lane-controlled signals share the main coding element-color-with traffic control signals. In situations where a lane-controlled street or highway includes a signal-controlled intersection, some confusion may exist between the two installations, especially in view of the almost automatic, over-learned response of drivers to the standard colors of the traffic control signal.

In such cases, the engineer, in designing these installations, must pay close attention to their impact, especially insofar as relative detectability is concerned. Also, because these devices have, so far, been used relatively sparingly, and mostly in major metropolitan areas, the population level of a priori knowledge concerning their meaning, application, and use is not as high as it should be.

## Variable Signs

The previous discussion of signs is framed in terms of fixed-message, fixed-position signs. Because all signs do not fall into this classification, a discussion of other types is in order. Signs may be fixed position, variable message, or fixed message, variable position. However, in considering a sign at any one given location, the two types are analogous: a fixed-message, variable-position sign is a variable-message, fixed-position sign where the variation is between message and no message.

A message may be changed manually, by using any of a number of physical devices to obscure part or all of the message or to alter parts of it; it may also be changed electrically. In the latter case, except for a few instances of remotely actuated motor or solenoid-controlled shutter arrangements, the variation in message is obtained by selective illumination of message units and all of these signs fall into the internally illuminated category. (A new type of sign, using a number of different sign faces on a window shade type of roller has recently come on the market.)

In the case of fixed-message signs, the repeat driver builds up an expectancy of what the message will be,
and will often substitute this expected message for the actual message on first detecting the sign. Such behavior can lead to serious consequences, especially in those cases where the message variability consists of contingent messages for abnormal road or traffic conditions that may occur only rarely. Detectability, attention-getting value, and legibility are therefore critical factors for changeable message signs. It is also desirable that the signs be clearly differentiated in appearance, so that drivers' expectancies are structured toward the possibility of a change.

It is worth mentioning that considerable technological difficulties impede the achievement of these objectives. Changeable messages may be formed by a matrix of letters or words, a matrix of light sources that can be illuminated to form the various messages, or by selective illumination of alternate messages, either side by side or, if the message is formed from gas-filled tubing, superimposed. In all these methods, economic achievement of optimum letter size, spacing, arrangement, and luminance is not possible with present state-of-the-art techniques, and additional research on display methods is required.

## Miscellaneous

Several other means are used to display information visually, external to the vehicle.

Police Traffic Control.-Motorists receive information, usually of a regulatory kind, by perceiving actions and gestures of police officers, school patrols, and flagmen. The general discussion of the visual information transmission channel applies. Special attention should be given to legibility and detectability by using such means as high-visibility clothes, gloves, flags, paddles, and lights. Knowledge of the code, especially concerning the police officer's and flagman's hand signals, is essential, and must be structured into the drivers' a priori knowledge. Because, except for certain downtown intersections and permanent school crossing locations, this is generally a rare and unexpected source of information, drivers' expectancies should be structured by advance signing or other means.

Detour.-Detours present a special and critical information problem. The problems are compounded by extremely high micro- and situational performance demands of construction and maintenance operations that usually involve the use by traffic of inadequate facilities and the high degree of macroperformance uncertainty introduced by using detours.

All devices and principles discussed so far are used in various combinations, supplemented by high-visibility barricades, flares, cones, and flashers. Because detours are areas of extremely high information challenge, with a considerable probability of potential processing overload, optimization of all facets of aiding and elimination of all transmission of information low on the primacy scale is essential. Furthermore, because, except for signs, aiding devices used in this type of operation are mostly nonverbal, standardization of design and application of these devices is essential. To the extent that these devices are nonverbal, the information they present is coded, and a knowledge of the code must be a part of all drivers' a priori knowledge.

Others.-Such additional visual displays as emergency vehicle identification, slow-moving vehicle identification, and others must be in accordance with previously derived principles.

## Outside-of-Vehicle Display-Presented via a Sensory Channel Other Than Visual

There are basically two nonvisual sensory channels that are used external to the vehicle for the display of information: the vibro-tactile (kinesthetic) channel, and the auditory channel.

## Vibro-Tactile Channel

The vibro-tactile channel as a reception channel could fall into either this subsection or the one covering in-vehicle non-visual displays, because ultimately the information is received through the vehicle. The reason for discussing this channel in this subsection is that a direct physical link exists between the transmitter (rumble strip), the communication channel (the vehicle), and the receiver (the driver). In this case, the discussion of the "transmitter" refers to the rumble strip rather than to the vehicle. It is realized that the type of suspension and other relevant vehicle characteristics modify the information. However, any discussion relative to the way in which the vehicle modifies tactile information is beyond the scope of this report. The following discussion is applicable to rumble strips, although other tactile external-tovehicle displays exist (corrugated medians, raised lane markings, etc.).

Three main factors are to be considered: detectability, expectancy, and comprehension. It must be recognized that, because of its slow response characteristics and poor frequency response ( $F-4$ ), the tactile channel is not readily amenable to any sort of complex coding. Therefore, this display of information best serves as a warning and alerting device rather than as a carrier of verbal information.

1. Detectability-For the rumble strip to be detectable, it must create a stimulus of sufficient intensity (even after being attenuated by the vehicle) and duration to be detected.
2. Comprehension-The driver must possess the a priori knowledge to know what the perceived stimulus means.
3. Expectancy-The driver must possess the a priori knowledge to know what to expect after detecting the received vibro-tactile stimulus.

## Auditory Channel

The only other possible exterior sensory channel that can be used with any success is the auditory channel. External-to-vehicle formal aiding techniques using the auditory channel include such things as: (1) public-address systems, (2) railroad crossing bells, (3) drawbridge bells, and (4) sirens, and police whistles. With the exception of the public-address systems, all other auditory devices are general or specific warnings, for which the auditory reception channel is best suited ( $F-1, F-2, F-4$ ).

Because public-address systems are used only in situations where traffic is either at a standstill or moving very slowly,* this type of information display is considered only briefly. For the following reasons, auditory information of a verbal natüre exterion to the velicle should not be presented when traffic is moving at any appreciable speed:

1. The Doppler effect could distort the signal to the point where it became unintelligible, especially at high speeds and with a single fixed installation.
2. There is no expectancy to receive a verbally coded auditory signal exterior to the vehicle.
3. At high speeds, the information presentation time would be too short to receive anything more than a very short signal.

The following discussion is applicable to exterior vehicle auditory displays.

## Transmission Factors

1. Comprehension-The driver must possess the a priori knowledge to comprehend the meaning of the auditory display; he must know what a siren means, a bell, etc. He must know exactly what to do when confronted with a received signal.
2. Reception-Because the driver can miss a signal while driving at high speeds, there should be enough repetition to ensure his receiving the auditory display.
3. Loudness-The display must be loud enough to be received above traffic noise and/or within a closed vehicle. The display must also be remotely received, therefore requiring a strong enough signal to be received at a distance. This leads to the problem of requiring an extremely powerful auditory source, which is annoying to people within close proximity, and possibly also dangerous because it could permanently affect the ears of people close by.

## Reception Characteristics

1. Masking-Because of the required high loudness level there is little likelihood of masking the wrong signal. The warning signal probably will mask any other auditory display.
2. Localization-The human observer is poor at localizing an auditory stimulus ( $F-2$ ); therefore, to localize the source, the best thing to do is employ multi-modal redundancy as is presently employed at railroad grade crossings and at bridges.

The auditory extra-vehicular display is extremely powerful as a warning device, but the designer must be aware of the very severe limitations to its use both in terms of limited applications and the fact that it is worthless to the deaf driver. For this reason, it is recommended that multimodal redundancy be used in all cases where an auditory display is contemplated.

## SURVEY OF POSSIBLE AIDING TECHNIQUES

Because a technique is useful in aiding a driver in the receipt of information does not mean that this technique is applicable for all situations. However, it is presented to describe the manner in which such a technique could

[^51]be applied to fulfilling the particular information need if such aiding is necessary. Furthermore, owing to the rapid advances in technology, the selection of applicable techniques cannot be considered exhaustive.

Because no survey of this nature could include all of the driver-aiding techniques that have been considered, the techniques discussed or mentioned herein either exist, have been studied extensively, or are judged to be applicable to the satisfaction of some specific information need.

The discussion is limited to techniques intended to aid the driver while he is driving-that is, techniques to satisfy the micro-, situational, and macroperformance informational needs. For example, when the driver stops in a rest area and reads a bulletin board, uses a telephone, or otherwise obtains information he is operating outside the constraints of micro- and situational performance. Hence, these acts may be considered as being analogous to "pretrip" activities. The techniques of supplying such information are not dependent on being compatible with those necessary for the driver to perform tasks at higher primacy levels. Hence, no detailed discussion of roadside equipment is made.

The various means are discussed in relation to specific needs as arranged into the broad categories of Table F-1, which gives the fundamental message types that may be aided. It also indicates, qualitatively, the expected frequency of the message and its applicability (continuous versus intermittent), message content, and the prevailing sources where such messages may originate. The purpose behind the consideration of these techniques is to ascertain where they may, in specific cases, supply the information needed by the driver more conveniently, clearly, or in a more timely manner than via current means.

## Vehicle Elements-Displays

These informational elements originate within the vehicle and inform the driver of the vehicle's operating condition and what it is doing in response to his control actions. For the safe and convenient completion of his trip, the driver must be aware of the operating condition of his vehicle, or, at the very least, know when some vital aspect of its operation becomes abnormal. "Idiot lights" inform him only that "something has gone wrong," and ordinary dials may not command sufficient attention. Hence, it is suggested that the concept of an integrated display of a number of the more important variables be considered.

The benefits of an integrated display have been investigated and used in aircraft applications-particularly in one-man military aircraft where the pilot must perform the duties of pilot, navigator, engineer, and weapons system officer. This type of display allows the user to tell at a glance whether the variables being monitored are within their proper range of values. This is accomplished by stretching or contracting each scale until they are all of approximately equal length, and arranging them so that, when the indicators are all at or near their proper values, all the indicators fall in a straight horizontal or vertical line (depending on whether the displayed scales are vertical or horizontal, respectively). The viewer need merely note

TABLE F-1
MESSAGE DESCRIPTION

|  | $\begin{aligned} & \begin{array}{l} \text { Short } \\ \text { Term } \end{array} \\ & \underline{C} \quad \underline{I} \end{aligned}$ | Time |  |  |  | Content |  |  |  | $\underline{\mathbf{v}} \quad \begin{aligned} & \text { Ext. } \\ & \text { Aid. } \end{aligned}$ |  | Sources |  |  |  | $\begin{aligned} & \text { Ed/ } \\ & \text { Exp. } \end{aligned}$ | $\underline{K}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{aligned} & \text { Inte } \\ & \underline{m e} \\ & \underline{c} \end{aligned}$ |  | $\begin{aligned} & \text { Lon } \\ & \text { Ter } \\ & \mathrm{C} \end{aligned}$ |  | Verbal | Quant. Num. | Qual. Symb. | $\begin{gathered} \mathrm{Go} / \mathrm{G} \\ \mathrm{No}-\mathrm{Go} \\ \hline \end{gathered}$ |  |  | Tk | A | $\underline{\text { P }}$ | C |  |  |
| Vehicle elements |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Acceleration (positive and negative) | x |  |  |  |  |  |  | $x$. |  | x |  | $x$ | x |  | x |  | x |
| Handling qualities | x |  | $x$ |  |  |  |  | x |  | x |  | x |  |  | x | x | $\mathbf{x}$ |
| Operational condition |  |  | x |  |  |  | x | x | x | x |  | x | $x$ | x | $x$ |  | x |
| Speed | x |  | x |  |  |  | x |  |  | x |  |  | x |  |  |  |  |
| Gasoline management |  |  | x |  | x |  | x | $x$ |  | x |  |  |  | x | x |  |  |
| Road elements |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Alignment (horizontal and vertical) | x |  | $x$ |  |  |  |  | x |  | x | x |  |  |  |  |  |  |
| Cross section, changes in | x |  | x |  |  |  |  | x |  | x |  |  |  |  |  |  |  |
| Lane(s), width, number of |  |  | x |  | x |  | x | x |  | x | x |  |  |  |  |  |  |
| Obstacles, on highway and nearby | x |  | x |  |  |  |  | x |  | x | x |  |  |  |  |  |  |
| Surface, surface condition | $x$ |  | $x$ |  |  |  |  | x |  | $x$ | x | x | $x$ |  |  | $x$ | x |
| Traffic elements |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Pedestrians | x |  | x |  |  |  |  | x |  | * |  |  |  |  |  |  |  |
| Traffic in adjacent lanes (fore and aft) |  |  | x |  |  |  |  | x |  | x |  |  |  |  |  |  |  |
| Traffic in lane (fore and aft) |  |  | x |  |  |  |  | x |  | x |  |  |  |  |  |  |  |
| Speed (relative to other traffic elements) | x |  | $x$ |  |  |  | x | x |  | x |  |  |  |  | x | $x$ |  |
| Gaps and lateral separation |  |  | x |  |  |  | x | x |  | x |  |  |  |  | x | x |  |
| Cross traffic | x |  | $x$ |  |  |  |  | x | x | x | x |  |  |  | x | x |  |
| Oncoming traffic | x |  |  |  |  |  |  | x | x | x |  |  |  |  | x | x |  |
| Traffic, general (level of service) |  |  | x |  | x |  |  |  |  | x | x |  | x | x |  |  |  |
| Advisory, restrictive, inhibitory |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Services, attractions |  |  | x |  | x | x |  | x |  | x | $x$ |  | x | x |  |  |  |
| Cautionary |  |  | x |  |  | x |  | x |  | x | x |  | x |  |  |  |  |
| Informative |  |  | x |  | x | $x$ | x | x | x | x | x |  | x |  | x |  |  |
| Limiting or restrictive (speed, direction, lane, size or type vehicle) |  |  | x |  |  | x | x | x | x | x | x |  |  |  |  |  |  |
| Rules of the road, general (a priori) |  |  |  | x |  | x | x | x | x |  |  |  |  |  |  | x |  |
| Rules of the road, specific (local) | x |  | x |  |  | x | x | x | x | x | x |  |  |  |  |  |  |
| Directive/restrictive signs and signals | x |  | x |  | $x$ | x | x | x | x | x |  |  | x |  |  |  |  |
| Directional |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Destination, final and intermediate |  |  | x | $x$ |  | x | x | x |  | x | $x$ |  |  | x |  |  |  |
| Decision points . |  |  | x |  | x | x |  |  |  | x | x |  |  | x | x |  |  |
| Direction: compass ( $\mathrm{N}, \mathrm{S}, \mathrm{E}, \mathrm{W}$ ), highway name, highway number | x |  | x |  | x | x | x | x |  | x | x |  |  | x | x |  |  |
| Distance to. . ., direction to. . . |  |  | x |  | x | x | x | x |  | x | x |  |  | x |  |  |  |
| Other directional/advisory (alternate route, detour, etc.) |  |  | x |  |  |  |  |  |  | x | x |  | x |  | x |  |  |
| Environmental |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Distractions, on and off highway | $\times$ |  | x |  |  | $x$ |  | x |  | x | x | $x$ | $x$ |  |  |  |  |
| Weather factors | x | x |  | $x$ |  | x |  | x | x | x | x | x | x | x | $x$ | x | x |

кеу:
$\mathrm{V}=\mathrm{V}$ isual
Ext $/$ Aid $=$ External, aided
Tk = Tactile
A = Auditory
$\mathrm{P}=$ Planning

C = Cognitive
Ed/Exp $=$ Education, experience
K = Kinesthetic.
$\mathrm{C}=$ Continuous
$\mathrm{C}=\mathrm{Cominuous}$
that the indicators are all aligned and does not have to concern himself with the actual values being indicated. If one of the indicators "staggers" out of line, it will be obvious and the viewer can direct his attention to it, note the values involved, and ast on the information thus received.

There are various ways of implementing such displays; two suggested ways are shown in Figure F-1. Figure F-1A shows four quantities being monitored: engine temperature, oil pressure, electrical power management (state of battery), and amount of fuel remaining. The nature of this display is such that the indicators are fixed; the scales, superimposed on a color code, move up and down. The viewer (driver) needs only to note that the indicators are all "in the green," denoting that each variable is in the
range of acceptable or safe values. If at any time he notes that one of the indicators is in any color other than green, he can read the numerical value of the abnormality. This suggested scheme also incorporates warning lights as an additional attention-gelling feature. When any of the quantities involved fall "in the red," the appropriate label is back-lighted by a flashing red light. A buzzer can be incorporated for additional emphasis.

Thus, this display system contains all of the elements of indicator lights, the scaler indication of the values of the variables being measured, a qualitative indication of normal/abnormal operation, the attention-getting feature (flashing light and/or buzzer), and ease of monitoring.

Fundamentally, the color scheme suggested is such that all "normal" or "nominal" values of the scale are green;

VEHICLE OPERATING CONDITION


MULTIPLE INSTRUMENTS - "ALL IN THE GREEN" FOR NORMAL INDICATION. MOVING RIRRON PLUS WARNING FLASHER


Figure F-1. Suggested automobile instrumentation arrangement.
"danger" areas are red; and transition from "normal" to "abnormal" may be gradual or go through a cautionary yellow range. The colors chosen should be, when possible, suggestive. Therefore, temperature, should be color-coded blue for "cold," gradually changing to green for "normal," and further gradually changing to red for "hot."

Figure F-1B shows a somewhat simpler system of information presentation. Three variables are monitored: engine temperature, battery, and oil pressure. Whereas the moving ribbon, fixed indicator type of display would be novel to the automobile, the three gauges shown are common, presently existing gauges. The only modification suggested is the addition of the appropriate color coding and the positioning of the gauges in such a manner that when all values are normal, all of the needles point (more or less) straight up. This practice is not new (F-15); some truckers who must monitor not only the ordinary engine instruments but also additional variables (air brake pressure, hydraulic pressure, etc.) find it expedient to rotate ordinary gauges normally supplied with the vehicles in a manner such as to achieve the "straight up" indication when all of the quantities are within the prescribed limits. It does not matter that the numbers on the gauges are turned or inverted; if the driver needs to read the number he can do so. Usually, however, one glance suffices to tell him that "all systems are GO," as signified by all needles being in the up position. The suggested display would have this quality, the qualitative features via color coding, plus the numerical values (if they were needed). (Dial faces can, of course, be color-coded similar to the moving ribbon described previously.) Additional attention-getting devices could be added.

Undoubtedly, many different variations are possible. Thus, for example, the first display described could consist of fixed scales and moving indicators; the arrangement could be horizontal instead of vertical; the number of variables being monitored may be larger or smaller; etc. Obviously, the more variables to be monitored, the more beneficial an integrated display of this nature is likely to be. Such displays would satisfy most of the driver's information needs pertaining to the operational condition and gasoline management (Table F-1) of the vehicle at any time.

Much information pertaining to the handling and the operating condition of the vehicle is imparted to the driver kinesthetically, and there is a tendency on the part of designers to attenuate such information in the interest of comfort. It is certainly technically feasible to measure and display, perhaps on an auxiliary panel, a number of variables other than the primary ones (temperature, oil pressure, battery, fuel). These include: an indication of excessive heat buildup in the transmission, cylinder heads, differential, and brakes; excessive pull in the steering geometry; seepage of exhaust gases into the passenger compartment; and brake fluid level. It is suggested that such quantities be displayed on the indicator-light principle only-that is, a warning given only when a potentially dangerous condition occurs ( $F-16$ ).

An example of this is the "door open" warning, introduced recently. In this system, all car doors must be firmly
closed before the light is extinguished. The use of fiber optics ( $F-17, F-18$ ), as another example, allows all of the vehicle's exterior lights to be monitored. It is not suggested that the dashboard/instrument panel of the passenger vehicle be cluttered with a myriad of lights, dials, and other indications, but rather that much information be presented by means of well-designed and engineered displays of the types described.

A further technique currently under study is that of "heads-up" displays, wherein the required information is projected and displayed in such a manner that the driver has no need to change the position of his head or eyes to be informed.

## Road Elements

Information pertinent to road elements must originate with the road itself, or equipment thereon or nearby. Probably the most important element to the driver is alignmentspecifically, his alignment relative to the highway, lane, curb, center line, or whatever his desired "line" is. The fundamental tracking task is described elsewhere as being the act of following this desired "line." 'This is presently accomplished by visual contact with some easily perceived reference (e.g., the edge of the pavement, pavement markings, a series of delineators, curb, or natural delineation of trees or other vegetation). In the absence of such continuous reference cues, a reasonably straight course may still be maintained by visually proceeding toward a distant target, although not with the same accuracy.

## Buried Cable

The use of buried cables has been studied extensively and has been used experimentally. The technique is relatively simple: a cable is imbedded in the pavement, following the intended path of the vehicle. An alternating current is allowed to flow within the cable, thereby creating an electromagnetic field around the cable that builds up and collapses at the frequency of the alternating current. The vehicle is equipped with a sensing device that, fundamentally, consists of a pair of coils mounted approximately vertically over and on either side of the vehicle's center (assuming that the vehicle's center must track the cable). The field induces a voltage in both coils, which is related in magnitude to the coils' position relative to the cable. As long as the cable is centered and equidistant from the coils, the voltage induced therein will be equal; displacement of the coil assembly (i.e., vehicle) to one side or the other will result in a difference in such voltages, that can be related to the displacement. A thorough study of the dynamics of such a system is described by Barrick (F-19). Similar studies have been performed and implemented experimentally at the General Motors Research Center and elsewhere. The system described is referred to as a "Displacement Error" system, because the voltage indicative of the displacement of the vehicle from the cable is (for relatively small values of displacement) proportional to the displacement. Figure F-2A shows the relationship of the cable and the coils; Figure F-2B shows the curve of
the displacement/error voltage relationship that may be expected. No values are indicated, because they depend on the frequency of the current in the cable, number of turns in the coils, spacing of the coils, their distance from the cable, and other geometric and electrical variables.

Barrick ( $F-19$ ) explains the need for a third coil placed centrally over the cable, oriented in such a way that (for small angles) the voltage induced in the coil is zero when it is centered, and increases nearly linearly with the angle of deviation from the cable. The study also shows how the combination results in a dynamically stable and usable system.

The fundamental task of this device is to produce an error signal proportional to the deviation from the desired path. What is to be done with the signal depends on its intended use. Most of the experimentation thus far has been based on the automatic guidance principle, where the error signal is used to drive a servomechanism that actuates the steering mechanism to return the vehicle to its original position and drive the error signal to zero. The lateral position of the vehicle on the highway can be pre-sented to the driver either visually or aurally to ensure that he remains on the road, despite reduced visibility or lack of other external clues. Whereas it is not believed that extensive driving will ever be done solely by "following the needle," it may be a worthwhile technique to supplement visual clues where they may be lacking, as well as a possible transition phase in the evolution toward fully automatic guidance.

The advantages of the coils/cable system are relative simplicity and demonstrated capability of doing the job. The most obvious disadvantage is cost: both the cost of the vehicle equipment to the motorist, and the cost of burying the cable. Obviously, to realize significant benefits from such a system, many miles of highways would have to be instrumented.

## Optical Trackings

Because it is easier to paint a white line on the roadway than to bury a cable, optical tracking is frequently mentioned as a technique that may be applicable. The basic technique is similar to that of coil and cable, except that a photocell measures the error instead of a coil. Also, analogously, a pair of cells or a row of cells might be considered for use to give a good indication of the change and the direction (left or right), or a single cell might be used "looking" at a dark space between two broken white lines, with the distances between the line segments coded to indicate "left error" or "right error." Principles underlying optical tracking of this nature are used in industry for counting, actuating machinery, and other tasks demanding detection of the change in light level as a result of (for example) an object passing directly in front of the cell.

The problems of the outdoor environment, the detrimental effect of tire wear on pavement paint,* the effects of highly variable ambient lighting, and the effects of weather (snow, slush, rain, and ice) tend to make the practical

[^52]


Figure F-2. Buried cable.
application of optical tracking somewhat unlikely. However, the simplicity of the vehicle equipment and ease of road marking dictate the consideration of this technique.

## Surface Condition Sensing

The techniques available for this purpose are directed chiefly at sensing the actual presence of, or possibility of, ice on the pavement, and giving the driver sufficient warning so that he can adjust his driving technique. The fundamental technique involves sensing the temperature and moisture content in the air at the pavement surface. When conditions for ice formation are favorable, the appropriate alarm or display is actuated. Such a system has been evaluated on I-95 near Augusta, Me. ( $F-20$ ), and has been used on bridges elsewhere ( $F-21$ ). For the most part, the alarm actuates a sign bearing the appropriate warning; for exampel, bridge icy or bridge wet. A variation of this is also available, whereby the sensor is mounted on the front of the car and the information is provided to the driver in the vehicle, either visually or aurally. Such equipment is currently available on the British Rover 2000.

The obvious advantage of using vehicle equipment for this purpose is that the driver has ice-warning information with him wherever he drives. Of course, the burden of the equipment is on him, as well as any maintenance of the
equipment. Furthermore, there is some question of whether the information would be received in sufficient time.

There are other means for conveying the information to the driver, even from roadside equipment-specifically, by radio. Either induction radio or commercial broadcasting can be used for this purpose. The former would demand the installation of the appropriate transmitting equipment wherever the message might have to be received, as well as the availability of the appropriate receiver in the vehicle. The latter would actually be a "demand" system; the driver would have to be informed either a priori, or periodically along the highway by means of signs to tune to xxxxkc For road information. Of course, the broadcasting agency would have the task of monitoring the ice detectors. That is, in fact, done routinely by commercial stations in larger metropolitan areas in a gross manner as a part of their regular programming, along with reports on congestion, accidents, and location of police radar.

Other surface-condition information generally refers to items such as those induced by past, present, or impending construction, or natural events such as flooding, and landslides. Because the locations of these events vary widely, it is suggested that commercial radio would be best suited to convey this information to the driver. Induction radio might also be applicable, provided that it could offer the necessary information to him at a location where he would have the alternative to choose another route. (It would be of little value to the driver to be informed that the highway is blocked by a landslide, while viewing the scene himself, with nowhere to turn around.)

## Highway Configuration

It is frequently necessary to inform the driver that the highway configuration is about to change. Examples are: transition from limited access to nonlimited access with grade crossings, changes in cross section such as lane drops, etc. Presently, this is accomplished by signs, and occasionally is reinforced by flashing caution lights. It is suggested that these conditions lend themselves to an approach that either will alert the driver to the visual message presented to him or will present the message to him directly, within the vehicle. Either technique requires message transmission from the roadside to the vehicle.

The driver could be alerted to visual messages by a strong, directional signal impinging on a vehicle-mounted receiver (a photocell if the signal is visible light) that in turn would activate an internal attention-getting device: aural, visual, or kinesthetic. For direct presentation of the message in the vehicle, he could be alerted most readily by induction radio. It is also feasible to activate, by means of a suitably coded signal, the playback of one of several prerecorded messages stored within the vehicle. However, this limits the messages to those anticipated and does not provide the freedom of induction radio, which allows any voice message to be transmitted.

## Traffic Elements

These information elements can be divided substantially into two major groups: (1) those for which information
will originate directly or indirectly from the highway (pedestrians, cross traffic, level of service), and (2) those where information must originate directly or indirectly with other specific vehicles in the traffic stream.

## Highway Originating Information

In an informal way, the information broadcast by commercial stations as a result of traffic observations from aircraft constitutes information about the level of service. The observer's report that ". . . the XYZ Expressway is congested . . ." is frequently followed by advice that ". . . the ABC Parkway may be a better alternative. . . ." Level of service to the individual motorist is certainly important, but he hardly needs to be told that he is in the midst of a traffic jam. What he needs is a forecast as to what he can expect further along his trip, so that he may use alternate routes, and information about these alternates. It is suggested that this type of information is most needed in metropolitan areas and should continue to be supplied by broadcast radio. However, rather than commercial stations, perhaps there should be a municipally operated station disseminating such information exclusively, based on more observers, at least during periods of heavy demand or abnormal conditions. The benefit of such an approach for a city such as Los Angeles, New York, or Chicago lies in that the station would not have to be extremely powerful, and would serve additionally as a useful tool to reach the citizens in the event of a catastrophe of major proportions, major accident, or some other city-wide problem (school closings because of weather or strike, garbage collection, parking regulations for the day, etc.).

The manner in which such an information scheme could be implemented (in terms of the region to be covered, information to be presented, means of ensuring that motorists receive the information intended for them, means of collecting the information to be disseminated and ensuring that it is timely and accurate) deserves further study, not only from the operational aspect, but also from the administrative and economic aspects.

Pedestrians present an entirely different problem. The driver expects to see pedestrians on some highways (city streets) and not on others (rural expressways) as part of a priori knowledge. The occasions when events counter to these expectations occur are those that carry the most danger for pedestrians and motorists. No reasonable solution to this problem is envisioned at this time. As for pedestrian visibility in sections where pedestrians are normally to be expected, in addition to the various visible signals, it is suggested that a suitable warning be presented to the driver within the vehicle. The primary benefit of such warning would be during reduced visibility (e.g., in rain or snow). The implementation thereof could be accomplished via roadside-to-vehicle equipment that would be useful for other information transmission as well.

Information pertaining to cross traffic is simpler in that it is easier to sense the presence of vehicles than pedestrians. Information signifying the presence or anticipated arrival of cross traffic can be suitably coded and trans-
mitted to the driver by any number of means previously discussed.

It is suggested that information pertinent to the existence of cross traffic and the existence (or likelihood) of pedestrians (where pedestrians can be expected) be aided by existing and proven techniques or combinations thereof. Information pertinent to the level of service on the route that the driver is likely to follow is more amenable to aiding by a centralized broadcast station serving a distinct area, supported by an integrated, coordinated, observation/ sensor network.

## Intervehicular Communications

The second category of traffic informational elements falls entirely within the framework of intervehicular communications (IVC). These may take place either directly between vehicles or with the intervention or cooperation of highway equipment. The information to be conveyed is highly dynamic and entirely situational in nature; it includes information pertinent to the vehicle's speed relative to other vehicles in the stream (both in lane and in adjoining lanes), gaps, lateral separation, and oncoming traffic (passing situation on two-way roads). Such information is at present being perceived visually and evaluated by the driver, with no aiding available. (On a two-way road approaching the crest of a hill or a curve, one could construe a no passing sign as being such aiding. However, this must be considered as advisory information, not situational. If the driver were assured by situational aiding that there was no oncoming traffic, he could pass safely. Such situational aiding is now being tested under the auspices of the Federal Highway Administration.)

It would appear that IVC should demand a considerable amount of vehicle equipment, although not necessarily, as can be seen by considering the rear-view mirror. Its chief function is to let the driver know what traffic behind him is doing. Hence, a considerable amount of improvement is possible merely by ensuring that the driver has a sufficiently wide field of view behind him, that there are no blind spots large enough to conceal another vehicle, and that the mirror itself does not obscure his forward vision. Convex mirrors increase the field of view; their placement relative to, and the shape and slant of the rear window likewise determine adequacy in this respect. The possibility of periscope-type optics also exists and is an important feature of the "Safety Car" design study by the Republic Aviation Division of Fairchild Hiller (F-23).

It is also possible, although not necessarily economically feasible, to use highway instrumentation to perform the sensing of vehicles, computations, decisions, and transmission of directives to the appropriate vehicles. Although such systems are not likely to become operational in the near future, an investigation of the basic technique may be worthwhile, because it may find specialized application; also, a determination of the operating characteristics of such a system will aid in understanding the dynamics of the driver/vehicle system. A detailed study of such a system was made at Ohio State University ( $F-24$ ). Similar to the guidance system discussed previously in conjunction
with the directional guidance technique, the technique studied aims at eventual automatic vehicle control.

The technique involves the placement of successive induction loops into each traveled lane; each loop is, in effect, the detection element of a presence detector. The associated electronics are envisioned as being buried next to each loop, and consist of the basic presence detector, logic circuits for calculating headway between successive vehicles, and appropriate interconnection with adjacent units. In addition, there is an induction radio transmitter to transmit headway intelligence to the vehicle in the loop at the time. Thus, the successive loops' zones of sensitivity break up the continuous lane into successive zones. Because the length of each zone is known and remains constant; because the entry, presence, and exit of each vehicle from each zone can be sensed; and because all successive zones are interconnected, the headway of each vehicle to the preceding vehicle can be calculated. Furthermore, from a study of the dynamic characteristics of the human driver in car-following situations, acceptable, marginal, and less-than-acceptable headways (consistent with safety) can be determined. The system theoretically operates by sensing the presence of each vehicle in the particular zone; each vehicle's speed is known, because its entry/exit from each zone is sensed; the occupancy or vacancy of the succeeding zone(s) is likewise available via the interloop connection. Hence, for each vehicle, both the headway and the rate of change of headway can be calculated for each particular vehicle. It is that information-that is, that the headway is increasing/constant/decreasing-that is transmitted via the induction radio to each particular vehicle and displayed. Roeca et al. ( $F-24$ ) suggest a qualitative modulation of the rate of change of headway, indicated by the intensity of the appropriately colored light (red for decreasing, green for increasing). By the appropriate interconnection of successive loops (or their associated logic modules), it should be possible to indicate the safety/advisability of passing even in conditions where forward visibility is normally not sufficient for safe visual passing.

This technique is complex; the costs of implementing it would be many times that of implanting a single cable in the pavement. The technique's chief usefulness presently lies in the better understanding to be gained of the driver/ vehicle dynamics and the resulting formulation of the control theory necessary.

Headway Measurement.-Assuming no roadside equipment, two approaches to measuring vehicle headway are possible: (1) with the lead vehicle equipped (cooperating), or (2) with the lead vehicle non-equipped (noncooperating). Cooperation in this context implies specialized equipment or quality in the lead vehicle, which is necessary for the following vehicle to extract the headway information. It may range from a device actually transmitting a signal to the presence of reflectors or other features on which the following vehicle's equipment relies. A technique exemplifying the cooperative approach has been studied by Treiterer ( $F-25$ ). The lead vehicle's equipment consists of a source of light (infrared) with a shutter arrangement (chopper) in front of it. The chopper is actuated at a frequency proportional to the speed of the
vehicle. Hence, the following vehicle needs only a photodetector and a decoding circuit that will sense the frequency of the pulses received from the lead vehicle and convert them to speed. Comparing the lead vehicle's speed with that of the following vehicle gives a measure and sense of the rate of change of headway. Note that so far no mention is made of the absolute value of headway-a most vital quantity-because a rate of change of 50 fps (equivalent to a closing speed of about 34 mph ) at 300 ft of absolute headway presents no great problem. However, the same closing rate at 30 - ft headway implies an impending collision in less than 1 sec .

In this technique, the intensity of the signal received is used as a measure of the absolute headway. Whereas this may be adequate under carefully controlled laboratory conditions, there are too many variables in the actual highway environment to rely on the accuracy based on this principle. Some of these are: varying ambient lighting conditions (these can be somewhat compensated for), attentuation of the signal due to dirt on the transmitter and/or receiver optics, and atmospheric attenuating agents such as fog, dust, and smoke. Thus, a technique that would not rely on the absolute strength of the signal would be preferable.

There are many theoretical means of measuring headway, or gap, although none has been studied extensively with a view to automotive application. First, it is suggested ${ }^{-}$that, to accomplish the measurement of absolute value of headway, there must be some known dimension on the lead vehicle of which a measurement of the subtended angle can be converted into range. This might take the form of two lights or reflectors, with standardized spacing for all vehicles. This could be accomplished in time, just as minimum headlight heights have been standardized by the industry. Having such a "base line" for the measurement, it remains to ensure that false alarms due to the perception of other lights, or combinations of one of the vehicle marker lights and a source within the environment, are minimized. A range of solutions for this purpose exists; one is color coding and filtering, and another is pulse modulation of the sources, electrically or mechanically, with appropriate filtering at the receiver.

The receiver offers a considerably greater challenge. It must have the capability of measuring a rather small angle accurately. Thus, if the receiver optics were such as to focus the image of the "base line" (as denoted by the two appropriately coded lights or reflectors) on a mosaic of photosensitive cells, it is a simple matter to calculate the error in range possible for any given angular resolution of which the device is capable. Assuming that it has a resolution of $0.1^{\circ}(6 \mathrm{~min})$, the possible error at a nominal range of $1,000 \mathrm{ft}$ would be 285 ft ; at 600 ft , about 140 ft ; at 200 ft , about 11 ft ; and at 50 ft , less than 1 ft . Note that the accuracy improves considerably at the closer ranges, a desirable property. The smallest array of photocells that exists at present is that used for paper tape readers; it is possible that smaller arrays will become available in the future.

A considerably more sophisticated method of measuring the angle may lie in the use of a horizontally rotating prism
or mirror such that the image of the "base line" is reflected on the photosensitive device in a scanning fashion, once per every revolution.* Thus, the images of the extremities of the "base line" will arrive at the photocell separated by the time interval required by the prism (or mirror) to turn through the appropriate angle (actually, one-half the subtended angle). A position (angle) encoder is used in conjunction with the rotating mirror; the reception of the pair of appropriately coded sequential pulses is used to trigger a measure of how far the mirror turns between such pulses; a relatively simple calculation converts this angle into the range desired. Because a system of this nature measures the absolute value of headway at repeated intervals, a smoothing function can be applied to a sequence of several consecutive measurements, and a rate of change of the range (headway rate of change) can be computed.

Fixed baseline ranging is fundamental to all optical range-finder techniques ( $F-26$ ); the use of lights, flash tubes, and infrared has been investigated ** for possible application to IVC, and experimentation is still being conducted at Ohio State University and elsewhere. Techniques involving rotating mirrors have been variously applied. Finally, shaft encoders and logic circuits to perform the required calculations are practically "off-the-shelf" items in the industry. Therefore, it is suggested that, even though the technique described has not been proven superior to others, it may prove feasible in one aspect of IVC: that of measuring both absolute headway and its rate of change. Its advantages are those of relative simplicity when compared to highway instrumentation concepts and its effectiveness on any highway, not only those previously instrumented.

Lateral Gap Measurement.--The measurement of the lateral gap in cases of parallel traffic streams presents somewhat different problems. First, the range over which measurements might be of interest is smaller than that for headway measurement. Next, rather than needing an absolute value of the lateral separation and its rate of change constantly, such measurements become necessary only when the lateral gap decreases to some minimum value consistent with safety. Finally, information on lateral separation from another vehicle one or more lanes removed is of secondary importance. The situations when such information might be important are those when the driver wishes to change lanes or when another vehicle begins to drift toward his vehicle. Presently, he relies on rear-view mirrors or a glance over his shoulder to ascertain the vacancy of the adjacent lane.

In any event, a Go, No-GO type of message, or DANGER indication when the adjacent lane is not vacant, might be all that is needed to supply this highly situational information.

[^53]When two vehicles approach each other to within a few feet, the ambient light level between them changes. This fact may be found useful, provided that the change can be detected with sufficient reliability by existing photosensitive devices.

Although radio frequency (RF) techniques are not considered advisable for lateral gap measurement, electrical ones may be found applicable. For example, a coil energized by a pulsating (or alternating) current will induce a similar measurable current in another coil of the proper orientation some distance (several feet) away. A simple stepping relay could energize the proper warning whenever the current level in the pickup coil exceeded some predetermined value signifying another vehicle closer than some predetermined distance. The obvious benefit of this technique is its simplicity; a possible disadvantage is that of releasing some of the electrical noise, to the detriment of other equipment. However, shielding may provide a partial answer. Furthermore, the noise commonly heard from internal combustion engines is ignition noise that, owing to the number of ignitions produced, falls well within the audible range; * hence, rather than using ignition current (such as from the primary of the coil) to energize the signal coil, an internal oscillator, doubler, or some other device might be used to raise the frequency above the audio range.

Because of its simplicity and economy, this technique warrants further investigation. In addition, if the technique should prove to be applicable to near-proximity warning purposes of other vehicles, it might equally be applicable to fixed objects near the pavement (e.g., bridge railings, and overhead structures supports).

The simple photocell/light source combination on opposite sides of the highway is useful for warning the driver of vehicle dimensions that exceed vertical or horizontal clearances ahead. This technique would allow the warning sign, audio sign, flashing light, or other device to remain inactive until a vehicle that exceeded safe dimensional limits broke the beam.

Presence Detection.-The various means of IVC discussed thus far consist, in one form or another, of various means of presence detection of vehicles. Presence detection techniques generally have been well developed, and a range of equipment, especially designed for this purpose, is available and in use, usually for actuation of traffic signals or counting. Their general characteristics are well known and need not be discussed in detail. Loop detectors, magnetic detectors, and ultrasonic detectors have been available for some years, and are available from a number of well-known manufacturers of traffic control equipment. Also, magnetometers, pressure pads and transducers, radar, strain gauges, and even infrared and television are usedthe last principally for study and/or surveillance purposes. The use of such readily available presence detection equipment in conjunction with the appropriate logic circuitry at the roadside might lend itself to performing the IVC functions required. Such application, which would demand great numbers of individual equipment, would presently

[^54]be limited by the costs involved rather than by major technical difficulties. Additionally, vehicle equipment for the highway-to-vehicle communications link would be required, placing the cost burden on the individual vehicle owner as well as on the highway operating agency.

Radio.-Thus far no mention has been made of RF techniques, even though much equipment of this type is on the market. Citizen's band equipment is readily available, with prices ranging from several hundred dollars to about $\$ 10$ for hand-held, walkie-talkie type of equipment. Mobile radio telephones also are available, as is a considerable selection of VHF and UHF mobile equipment. In addition, induction radio techniques have been used experimentally in a number of applications where limitedrange communications are required. In this context, it is necessary to distinguish between the "far-field" type of communications, which encompasses all of the former techniques, and "near-field" communications representing induction radio.
"Far-field" defines communications at distances beyond several wavelengths. At an average broadcast frequency of $1,000 \mathrm{kHz}$, one wavelength is nearly $1,000 \mathrm{ft}$; at the CB frequency of about 27 MHz , one wavelength is about 35 ft . The "far-field" laws generally hold some five wavelengths or more from the transmitter. "Near-field" phenomena accordingly prevail at lesser distances. All electromagnetic radiation consists of two distinct fields: the magnetic and the electrical. At "far-field" distances, the magnetic field is dominant, whereas at "near-field" distances the electrical field is dominant.

The application of "far-field" type RF communications equipment is not considered suitable for IVC purposes (traffic information), principally because the information transmitted by one vehicle is needed almost exclusively by vehicles with which it interacts directly in any form: headway, gap, lateral separation, etc. Such information would comprise "noise" to all other vehicles on the highway and in the area. Furthermore, even with UHF and its very short wavelengths (about 3 ft and less) to ensure "far-field" transmission, there is the technical absurdity of hundreds or thousands of vehicles transmitting; as a result, no one could receive anything (aside from the problems of line-of-sight transmission necessary for UHF).

One aspect of a type of IVC for which RF techniques are believed to be potentially applicable is emergency communications. Such programs are currently in existence; HELP and REACT are prime examples ( $F-29, F$ 30). These programs do not rely on communications between the affected vehicles so much as communication of the need for aid to some central location ( $F-31-F-34$ ) by motorists suitably equipped with the appropriate CB gear. It is suggested that in this context the inexpensive, CB, hand-held walkie-talkie units might be useful. These units generally have a limited range of about $1 / 4$ to $1 / 2$ mile, compared with 5 to 15 miles for ordinary mobile equipment. Such units might be useful for communicating the need for aid to either: (1) a fixed-base monitor station (such stations might be installed on telephone poles along rural highways and be equipped to relay the message either via RF or telephone lines to the appropriate authority/
agency); (2) another motorist who passes (thereby letting him be the carrier of the message to a reporting point, or relaying via more highly powered $C B$ equipment if he is so equipped) ; or (3) a roving monitor station in the form of a police patrol vehicle or a service vehicle ( $F-35$ ) (such as might be most frequently found on urban expressways/ freeways).

Induction radio techniques appear to offer little in terms of IVC application, except possibly via highway equipment. The salient aspect of the induction radio technique is that of transmitting a message that is receivable only in the immediate vicinity of the transmitting loop (antenna). In highway applications ( $F-36$ ), such loops are commonly placed on or near the shoulder, paralleling the highway, or imbedded in the pavement itself. To restrict the radiation largely to that receivable by the appropriate receiving equipment in the location for which it is intended, and to minimize the possibility of reception at greater distances, such placement leaves the electrical field virtually unaffected, while strongly attenuating the magnetic field. Furthermore, because the attenuation characteristics of the electric field energy increase considerably at higher frequencies (for a given distance from the loop), relatively low frequencies must be used; this implies relatively long antennas (long loops). Thus, the induction radio technique functions largely as a proximity device. If the basic signal (carrier) received is suitably modulated with usable intelligence at the transmitter, and demodulated when received, voice-type messages can be transmitted while the vehicle is near the transmitting loop ( $F-37$ ).

Experimental Techniques.-Whereas there may be any number of novel and interesting techniques under investigation for IVC, none has enjoyed more publicity nor is more glamorous than those employing lasers. An acronym for "Light Amplification by Stimulated Emission (of) Radiation," the laser is a device capable of emitting a very narrow beam of monochromatic, coherent radiation, usually in the visible spectrum. The frequency of radiation depends on the "lasing" element; those found most useful thus far emit in the red/infrared region of the spectrum, or at a wavelength of 8,000 to 9,000 angstrom units. It is this quality of coherence as well as the short wavelength (compared to RF wavelengths) that makes their application attractive. The extreme narrowness of the laser beam allows line-of-sight communications between the transmitter and the receiver with a minimum of interference (other than the interposition of another object). Radarlike techniques employing laser devices are being studied at this time. An experimental device has been built at MIT's Lincoln Laboratory that is capable of detecting the position and velocity of vehicles-and even pedestriansat distances up to 2 miles ( $F-22$ ). Other experimentation (much of it classified) is in progress for military applications, such as ranging, and secure communications.

Early laser work required high-voltage power supplies, flash tubes, and cryogenic temperatures. New developments have resulted in satisfactory laser operation at ambient temperatures. In addition, the development of junction laser suggests its application to the IVC problem. The junction laser is inherently much simpler, being funda-
mentally a diode, operating at ambient temperatures, and requiring no "pumping" action such as that of gas or ruby lasers. The power requirement is relatively low, as well; and lasing action is achieved merely by passing current through the diode. Amplitude modulation at very high frequencies is likewise possible (as high as 200 MHz ). Thus, the only additional equipment required is a current pulse generator.

In conjunction with junction (often referred to as "injection") lasers, diode photodetectors with good sensitivity and frequency response are available. Using these components, some development work has been performed successfully at the research agency ( $F-27$ ) in conjunction with the detection of disabled vehicles by means of a junction diode, infrared source on the vehicle, and a diode detector at the roadside. Also, an experimental system employing similar components has been devised for the purpose of vehicle-to-highway-to-vehicle communication to actuate traffic signals selectively so as to give priority to the vehicle thus equipped (e.g., bus, emergency vehicle). Other research activities, oriented directly toward IVC, are currently in progress elsewhere.

## Advisory, Restrictive, and Inhibitory Information

Table F-1 indicates that the informational elements fall generally into the following categories:

1. Absolutely Mandatory Information-This is information the driver must have at all times and includes the general rules of the road. It is a function of the driver's education. Obviously, no on-site or in-vehicle aiding can effectively overcome any shortcomings in this area. However, there are local rules with which the driver may not be familiar, and, here, aiding is required.
2. Situationally Mandatory Information-This is information the driver needs for specific situations and includes limiting or restrictive information, where such applies (e.g., no trucks, one way, or no entrance).
3. Occasionally Required Information-This category includes cautionary information, such as the existence, or potential existence, of a hazard (e.g., deer crossing, falling rocks), generally informative matter (e.g., ENtering orange county, there are no services on this highway), and service availability information.

## Absolutely Mandatory Information

Because it is important that each driver receive absolutely mandatory information, any technique used must not rely on the driver's desires or on any particular action on the driver's part. Thus, if broadcast radio is considered (e.g., state-wide, or metropolitan area-wide coverage) for this purpose, it must be supplemented by the assurance that the affected drivers are in fact listening, either by virtue of all the radios being on whenever the ignition is on, or by the legal requirement to "Have radio tuned to $\mathrm{xxx}^{\prime}$ while within the confines of the area where the information applies. Although all automobiles are not radioequipped, more than 80 percent are. Furthermore, there is a precedent in flying, where controlled airports cannot
be entered by aircraft without radios (except in emergencies).

Thus, broadeast radio could be used as an aiding technique, possibly even with minimum additional vehicle equipment. An alternative means lies in requiring the use of a simple, single-frequency receiver that the driver would have no option to turn off. The availability of inexpensive and reliable solid-state broadcast receivers suggests this as a practical possibility.

Similarly, induction radio techniques, previously discussed, could be applied in cases where the information to be presented has significance only at selected, fixed locations, or on limited highway segments. A modification to the existing broadcast receiver, at least, and probably a special receiver to receive such transmissions, would be required.

## Situationally Mandatory Information

Situationally mandatory information must be presented to the driver with minimum action on this part to receive it. An example of such situations is an exit ramp from an expressway or freeway, oriented in such a way that it could be mistaken for an entrance, particularly if a motorist should happen to miss or disregard the various forms of Wrong way signing used. In this case, induction radio techniques, as in the previous case, could be exceedingly helpful. The implementation would consist of a vehicle detector (directionally sensitive) that, on sensing a vehicle proceeding up the ramp the wrong way, would switch on the induction transmitter. A very urgent prerecorded message directing the driver to stop, and the reason therefor, would then be transmitted. Simultaneously, flashing lights and other means ( $F-38$ ) aimed at discouraging further progress by the "wrong-way" motorist can be actuated, along with appropriate warning devices to warn other drivers who may be about to enter the ramp properly.

Induction radio is not mandatory in this case; the actuation of the various lights, flashing signs, and possibly even accoustical devices such as a siren, might be accomplished directly by the logic sensing the presence of the "wrongway" vehicle.

Several papers have been presented recently dealing specifically with the oncoming traffic problem. Obviously, the passing situation applies primarily to two-lane, twoway roads rather than Interstate-type highways. However, one can foresee the condition when advance warning of a lane being occupied (for example, over the crest of a hill, around a "blind" turn) to approaching traffic would be beneficial, much as warning of oncoming traffic in the absence of visual contact would make passing possible where it is not safe without such aids. Six papers of a previously referenced symposium ( $F-28$ ) deal specifically with various aspects of the passing situation. A potentially practical suggestion to aid in the passing situation was made nearly ten years ago, based on the sensing of the vehicle's presence and actuation of appropriate devices (lights, signs) ahead of it clearly visible to oncoming traffic ( $F-39$ ), even though the vehicle itself may not be in view.

## Occasionally Required Information

Cautionary Information.-Information pertinent to potential hazards can be most effectively aided by being presented only in the event of a high probability of the hazard actually existing. Thus, for example, a fixed sign stating trucks entering, whether trucks are likely to be entering at the time or not, is not nearly as effective as one that becomes visible only when such activity is, in fact, in progress. The same can be said about deer crossing, rock slides, ice on bridge, etc. Whereas there is no known equipment to accurately predict the probability of a rock slide or when deer may cross a highway, there are many other conditions that can be predicted, such as MEN working, flood area, slippery when wet, and cross traffic.

The techniques applicable depend on accurately sensing and predicting the likelihood of occurrence of the hazardous situation. Also, subsequent actuation of signs/signals/ audio warning devices, or even the verbal transmission of cautionary messages via induction radio transmitters, presupposes that most vehicles are equipped to receive such messages. Detection of moisture and traffic is discussed elsewhere. In cases where the potential hazard is manmade (e.g., construction activity), the appropriate warnings can be man-actuated.

Seismic techniques for the detection of major shifts in earth masses might be applicable to sense the onset of slides or major rock falls in areas where such are most likely to occur. Finally, and this is currently being done, when regional or state-wide highway hazards are prevalent or likely to occur, commercial broadcast stations inform their listening public via regular newscasts and special announcements. Such information presently is "demandtype" information, because the driver must voluntarily turn his radio on and listen.

Steps toward unifying and assuring completeness of such information transmission are being tried in some localities. One such method is the allocation of some one frequency to a municipally operated station to broadcast pertinent travel information exclusively-the motorist being notified thereof by periodic visual reminders to "Tune to xxxx on your dial for travel information." Another is currently under study in a major metropolitan area and aims at consolidation of all of the observation aircraft and their reports for a continuous, city-wide reporting system. Presently such observation is carried out by commercial radio stations in New York, Los Angeles, Chicago, and elsewhere, none of which, with the limited number of units that they can afford to use, can give continuous coverage by themselves.

Service Information.-Service information and information pertinent to local attractions, more than any other, appear to fall into the demand category. This means that such information should not be presented unless it is needed by the driver ( $F-27$ ). This is particularly true of service information, because local attractions frequently compete for the motorists' patronage, and notification thereof constitutes advertising. However, unless the driver requires services for himself or his vehicle, or foresees
that he will require such services in the near future, service information is of little interest to him and thus constitutes "noise."

The information can be presented to the driver aurally, within the vehicle, visually from the roadside, and visually or aurally off the highway. Aural presentation again implies induction radio techniques where, at suitably designated locations, the driver would receive prerecorded messages pertaining to the availability of services at the next exit, crossroad, or within so many miles. The demand function might be fulfilled in two distinct ways: (1) by the driver actuating his receiving equipment when he is in need of services information, with such information being transmitted continually, and (2) by triggering the transmitter in the case of such a need arising. The triggering could likewise be accomplished in a number of ways.

Visual presentation of services information "on demand" can be actuated in identical ways. However, because the driver's reading time is limited, it is suggested that rather than presenting information pertinent to all conceivable services, information pertinent only to the type of service desired will be presented. This would merely demand a coding of the actuation (triggering) mechanics; for example, three distinct trigger sequences for each of the three fundamental types of service-fuel, food, and lodging. On receipt of the appropriately coded "demand message," the roadside equipment would actuate the appropriate sign ahead (e.g., via back-lighting or backprojection) for a period of time sufficient for the passing driver to read and comprehend the information thus presented.

Induction radio techniques can employ the same principle (supplying information about the desired service types only) by the simple expedient of recording the information on three parallel tracks, and playing back only the one demanded. Both for the induction radio and visual display (sign), further refinement (and complexity) is possible, although perhaps not economically feasible.

Perhaps the most advantageous manner of presenting service information is by presenting it off the road so that the driver could be exposed to more detailed information for as long as he wishes, while not engaged in the driving task. On the Interstate system, the ever-increasing number of rest areas appears to offer the answer ( $F-30, F-31$ ). However, once the driver stops at a rest area, the spectrum of his information needs changes completely, because the first three categories of information needs (vehicle elements, road elements, and traffic elements) cease to exist for the duration of his stop. Hence, a discussion of the various techniques of presenting service information to him during this time is beyond the scope of this study.

In concluding the discussion of some of the ARI (advisory, restrictive, or inhibitory) aiding possibilities, it should be noted that it is at this level than an "on-demand" type of presentation has been suggested as being first applicable to any extent. It also should be noted that more and more of the techniques previously discussed as being potentially applicable to informational needs higher on the primacy scale are found to apply here.

## Directional Information

In considering various aiding techniques for presenting directional information (other than by means of standard fixed signs, which are discussed elsewhere), several techniques are of interest.

Before discussing some of these, it should be pointed out that directional information even more than ARI information is suited to "on-demand" presentation. In other words, at any given decision point, the driver usually is interested in only one of a number of possible alternatives, as per his trip plan. All other potential destinations at that time (to him) constitute "noise." Therefore, the mechanics of "interrogating the decision point" (i.e., transmitting the demand for specific directional information) deserves even more attention in this category of informational needs.

## Decision Point Interrogation

The fundamentals of the techniques available for the purpose of communicating the need for information from the vehicle are discussed elsewhere: light (visible, infrared.), radio ( RF ), and acoustical. Each has its advantage and shortcomings. Except for the use of the existing headlights (visual light) or horn (acoustical, audible range) all of the other techniques require specialized vehicle equipment to "transmit" (via infrared, RF, or ultrasonics).

The degree of coding of the "interrogation" signal to be transmitted determines, to a considerable extent, the complexity of the vehicle equipment. Thus, consider the least expensive alternative: that of flashing of headlights. The degree of modulation is limited to the driver flashing them ON-OFF or HI-LOW, two or more times, while within the field of view of the detector. Hence, the "message space" is limited to transmitting only one message." The same can be said for the use of the existing horn (it is also suggested that use of horns in or near urban environments is not recommended).

Hence, the utility of a system subject to such limitation is confined to the request for the presentation of all possible items of information (of some particular kind); for example, all possible destinations served by an exit, or (as discussed before) all services available. In considering, however, that each decision point (interchange or intersection) serves many destinations (or subsequent decision points), more complex coding appears to be a necessity. Therefore, specialized equipment for interrogation purposes would be necessary.

Furthermore, the degree and the most advantageous type of coding of the interrogating signal necessary will be determined by the manner in which the possible destinations are coded. Thus, the only directives to be given might be the cardinal directions; for a complete description in binary language, this would require four symbols of two bits each. (Of course, this information is hardly believed to warrant the complexity of a demand system; it is used merely as an example of the coding possibilities.) Similarly, in using a tone-coded signal, four distinct tones would have to be employed, or four sequences of two

[^55]tones, each sequence being analogous to the binary symbol. The demand signal then would represent a request for an indication of one of these directions.

The subject of destination coding is discussed elsewhere and is the subject of studies currently in progress at Philco-Ford; ways of implementing the same are being studied by the General Research Laboratories and GM's Delco Division. The basic coding scheme has been developed by Philco in cooperation with the BPR (F-42) and works, basically, as follows.

The entire United States is divided into 20 Regions; each region consists of 25 Districts; each district is divided into 20 Sectors; each sector is divided into a number of (up to 20) Zones, with each zone containing 25 Intersections. It is presently planned to thus code about 4.5 million intersections. This description should give a fair indication of the complexity of the coding process involved. The minimum requirement to code, in binary notation, each such destination would be about 20 bits. For this reason, coding can be simplified by presenting each destination in the form of a distinct sequence of symbols, where the first describes the Region, the second the Zone, etc., and the last the Intersection. Because the largest number of subdivisions in any unit is 25 , a 5 -bit symbol suffices to code each of these. Hence, all of the nearly 5 million intersections can be described by distinct sequences of five 5 -bit symbols, each.
But whether this coding system is used, or any other that might be developed, the vehicle equipment can be seen to require considerable sophistication. It is also evident that the transmission of such complex messages cannot be accomplished manually by the driver accurately and reliably while driving.

## Directional Information Presentation

The possibilities of such presentations range from completely automatic guidance of the vehicle to its destination, to successive directions being given to the driver to "turn left," "exit here," etc., that he is expected to follow. Any system of this type is predicated on the use of considerable amounts of roadside instrumentation. There is likewise a range of means by which the information may be presented to the driver, including: selective actuation of signs for his visual perception, aural instructions, displays within the vehicle, or not at all (as in completely automatic guidance). Some of these are considered in the following.

Induction Radio.-One possibility is to place an induction radio transmitter before a major decision point. The prerecorded message would contain a list of the various major destinations served by that decision point (and could also include, for example, service information), much in the manner of the railroad conductor walking through the cars on approach to a station intoning the name of the next stop. The information would be verbal and would be received on actuation of the transmitter via the vehicle's "demand" link. This approach appears to be one that might be suited to use the rather simple "demand" system -whereby the transmission from the vehicle merely actuates the roadside directional information system. This
approach also has the advantage of the roadside equipment being relatively simple; there being no logic/data processing involved at the roadside. For each transmitter, there is only one message sequence that must be prerecorded individually and played back on receipt of the "demand" signal.

A step toward more complexity would be taken with a demand signal system capable of a limited number of distinct demands; for example, signals representing requests for (1) directional information and (2) services. The roadside equipment must be capable of discriminating between the two signals, and play back the track containing the appropriate information.

The aforementioned directional coding and guidance system (under study under Bureau of Public Roads auspices) likewise is intended to make use of induction radio principles for vehicle-to-roadside and roadside-to-vehicle communications. However, the application as presently planned will differ from the previously described possibilities because: (1) the demand signal will consist of the destination code and, (2) the roadside equipment will contain the appropriate electronics to receive and decode the demand signal, select the route to be followed from the particular decision point to the desired destination, and transmit the appropriate directive back to the vehicle. The signal received in the vehicle is decoded and (as presently envisioned by the researchers) displayed as one of a number of symbolic directives: straight, turn right, etc. Each intersection (decision point) would thus have to be instrumented. The driver would merely need to insert his destination code into the vehicle equipment; the subsequent interrogation, computations, and display would be automatic.
Probably the ultimate application of induction radio techniques would involve automatic vehicle guidance whereby, instead of displaying guidance information for the driver to act on, steering and acceleration/deceleration inputs would be applied to the vehicle, leaving the driver out of the control loop as long as the vehicle remained on the instrumented highway system. Induction radio techniques, along with those of cable or successive loop guidance techniques, would have to be used.
Broadcast Radio.-Because directional guidance is such that each vehicle requires individualized instructions on how to proceed (assuming that each vehicle has a unique destination) at each decision point, broadcast radio is believed to be unsuitable because, by its nature, a broadcast message is intended to be received by a large number of listeners. However, as discussed earlier, broadcasting is applicable to directional information that may affect a great number of motorists; for example, alternate routing suggested because of reduced level of service on the primary route.

In-Vehicle Presentation of Directional Information.In conjunction with the radio techniques mentioned, two ways of presenting directional information were mentioned: verbal audio, produced within the vehicle, and symbolic visual, displayed within the vehicle.
There are many other techniques for displaying directional information within the vehicle. Thus, the symbolic information may be projected and displayed in the driver's
line of sight ("heads-up" display); it may be displayed on a panel supplied especially for this purpose; and, finally, the symbology may be simple, consisting of simple lights (perhaps different colors), or it may employ reproductions of actual familiar symbols (such as arrows). Should it be found advantageous to present aurally symbolic directional information, such information could be tone coded; * alternately, the symbology could trigger playback equipment (magnetic tape) containing a prerecorded set of all possible directional messages that might be received from the roadside. This is feasible provided that the number of possible messages is finite (e.g., TURN RIGHT, TURN left, No services at this exit, take this exit).

Mapping likewise represents a form of symbolic directional information presentation. However, excluding the presence of a "co-pilot," the driver cannot comfortably consult a map while driving. To make this task easier, a moving map display technique might be applicable. This technique was developed some time ago, originally for the benefit of pilots of cramped, high-performance, single-seat aircraft. The presentation consists of a moving map display with a small symbol in the middle of the display window/ screen representing the location of the craft on the map. Rather than storing a full-sized map, for convenience the map can be "compressed" on a transparency and only a small portion projected on the viewer/display. Thus, the apparent motion results from the slide being moved in front of relatively narrow angle optics. A system functionally similar to that described has in fact been developed in England by Ferranti, Ltd. ( $F-43$ ). It is suggested that a technique borrowing from this method, and perhaps employing a strip map of the route to be followed, might prove to be practical.

External Presentation of Directional Information.-With the exception of the printed map, directional information currently appears at the roadside in the form of road signs. Qualities of legibility, letter sizes, illumination, etc., are discussed elsewhere in this report. Several possible means of expanding on the capabilities of the fixed directional sign are mentioned, specifically in view of the suggested adaptability of directional information to being "ondemand" information.

For example, there is an obvious limitation on the amount of information that can be included on a single directional sign. However, with a demand system allowing for the coding of destinations, and back-projection techniques, it should be possible for the directional sign to show nothing, unless interrogated. Once interrogated, the appropriate information (such as name of the destination and directions and distance to it) can be projected, using the whole sign panel and thus assuring adequate letter size and legibility. If the destination asked for is not on the sign, a message (such as continue) could be flashed on briefly to confirm the receipt of the interrogating signal.

A novel approach to external information presentation is that using holography. Basically, holography is a means of producing photographic transparencies using coherent

[^56]light * that, when projected using coherent light, produce a three-dimensional image in space of the object photographed.

Holograms bear no resemblance to normal photographs but appear as patterns of light and dark areas. The patterns are produced when the coherent light reflected from the object combines with the coherent light from the source and expose a photographic plate.

Because holography requires the use of coherent light for exposure and projection, the laser has been found to be exceedingly useful for this purpose. However, not all of the incident light must be coherent; only enough to form the interference fringes. Therefore, it is possible to make and project holograms using monochromatic light sources (for example, a sodium arc lamp) or even sunlight filtered to create reasonably monochromatic light (which contains some coherence).

A preliminary study of the subject has been made for the BPR by Forster Industries, Inc. ( $F-44$ ). That report provides details pertaining to the holographic process and the mechanics involved. The advantages claimed in that study in using holography for highway signing, including directional information, are twofold:

1. It is possible to place the hologram itself at a safe distance from the highway and yet have the image appear where it is needed (e.g., in the gore or immediately next to an exit where safe placement of a physical sign may nưt le pússible).
2. Because the viewed image changes as the viewer's position changes relative to the image, it is possible to present information selectively (e.g., it may be possible to present advance exit information to left-lane traffic and directional information relating to the imminent exit to right-lane traffic).

Several excellent articles on holography have been written and are recommended ( $F-45, F-46, F-47$ ). Nevertheless, holography is a new phenomenon and remains practically unexplored, particularly for such potentially practical applications as highway signing. Further research in this area is needed and recommended.

## Systems Approach

Most of the techniques discussed thus far are concerned with singular information needs. Obviously, any aiding system would have its highest cost-effectiveness if it had multiple capabilities-that is, it should satisfy a number of the driver's information needs.

At this time, there is no single operational system that fulfills all of the driver's informational needs well.

Kelsey and Halstead ( $F-48$ ) discuss over-all communications needs, including such features as motorist information, emergency communications equipment (at the roadside and/or in the vehicle), induction radio techniques for two-way communications along the highway, remote control of highway signs, and the use of various traffic surveillance equipment for efficient traffic control.

[^57]Halstead and Kelsey ( $F$-37) favor the use of induction radio for a multitude of applications.

A rather comprehensive communications system that would combine many of the aspects of the possible techniques previously is discussed by Baner ( $F-29$ ). It considers a number of the driver's information needs and wants, and the means to satisfy them. One of the key aspects of the approach discussed is the application of the Radio Road Alert (RRA), whereby, when the need exists for some particular message to be imparted to the driver, a coded signal from the roadside is used by the vehicle equipment to select and play back to the driver the appropriate prerecorded message, a considerable number of which may be stored (this technique is discussed in conjunction with "directional information" in this appendix). This avoids the problem of fading with distance, noise effects (nearly so), intelligibility, and need for relatively complex roadside equipment (although at the expense of more complex vehicle equipment and higher cost to the individual vehicle owner). Other features suggested give the driver a voice communications link enabling him to ask for assistance or information. The HELP effort (Highway Emergency Locating Plan) is discussed, as are REACT organizations' efforts.

A somewhat parallel approach is found in GM's DAIR (Driver Aid Information and Routing) which is described by Hanysz ( $F-30$ ). This approach uses a number of novel and interesting techniques to satisfy the gamut of the driver's information and communications needs-from route guidance, through aiding in situational or ARI needs, to the availability of communications links (in the CB band) for emergency and informational use, in a unified fashion. Some of the more interesting approaches include the internal display of warning signs/signals on a special panel, and intersection coding by means of a precoded card (the insertion of which in the vehicle console results in directions at intersections being given to the driver symbolically). In addition, the driver has at his disposal the ability to call for a choice of services, simultaneously and automatically identifying his location to the recipient of the message only.

Undoubtedly, a number of other over-all systems are under study, partial (experimental) implementation, or envisioned. It should be kept in mind, however, that to gauge the applicability of the system (any one of the foregoing "complete" systems), to the existing or near-future vehicle/driver/highway environment, such a system would have to meet the criteria previously set forth. At the present state of the art, it is strongly suspected that nearly all of them would fail the "economic feasibility" criterion. Thus, for example, instrumenting the highway is extremely expensive. Furthermore, the benefit to the motorist increases proportionately to the percentage of the equipped highways on which he travels. Furthermore, all of the "complete" solutions demand more or less vehicle equipment in which the driver would have to invest. Of course, technology moves ahead at a considerable rate, and equipment that today may be prohibitive in cost may be replaced by units of equal or superior capability and reliability at a fraction of the cost.

## Conclusion

It is realized that there are many techniques, other than those previously mentioned, that may be considered worthy of study for potential application to the highway environment. Some of these may be related to those mentioned; others may be new. Many researchers have written papers describing utopian highway instrumentation systems employing many elements of the techniques briefly discussed here, usually within the context of the over-all highway system.

Whereas an over-all systems approach toward the ultimate implementation of any such instrumentation/communications/guidance system is, in fact, indicated, it must be remembered that such implementation cannot be of a revolutionary nature. Rather, the development must be evolutionary, and hence never lack compatability with the existing highway system, vehicles, or driver capabilities. This means that for long periods of time vehicles will have to be able to negotiate instrumented as well as noninstrumented highways-much the way they can currently use limited-access highways and country roads. Because the change in vehicle population will be gradual, so will the introduction of any specialized equipment thereon. Finally, the demands on the driver today are different from those of 30 years ago; it is fair to predict that they will be different 30 years hence. But the change will be gradual, not sudden, and the change from today's highway to the "highway of tomorrow" will not occur overnight by quickly installing instrumentation, modifying the vehicles, and reeducating the driver to the new environment.

## REFERENCES

F-1. Morgan, C. T., Chapanis, A., Cook, J. S., and Lund, M. W., eds., Human Engineering Guide to Equipment Désign. McGraw-Hill (1963).
F-2. Woodson, W. E., and Conover, D. D., Human Engineering Guide for Equipment Design. Univ. of Calif. Press, Los Angeles (1964).
F-3. Schmidt, I., and Connolly, P. L., "Visual Considerations of Man, the Vehicle and the Highway." Publ. SP 279, Soc. of Automotive Eng. (Mar. 1966).

F-4. Hulbert, S. F., The Application of Human Factors Research of Warning Devices for Highway-Rail Grade Crossings. Prepared for Alan M. Voorhees and Assoc., Planning and Eng. Sciences, Inc., Burbank, Calif. (1966).
F-5. Coppin, R. S., and Peck, R. C., "The Totally Deaf Driver in California." Hwy. Res. Record No. 79 (1965) pp. 35-44.

F-6. Rockwell, T. H., and Ernst, R., "Visual Requirements in Night Driving." NCHRP Report 99 (1970) 38 pp .

F-7. Dart, O. V., Jr., "Evaluation of Effectiveness of Roadside Delineators." Eng. Research Bull. No. 81, La. State Univ. (1964).
F-8. Manual for Signing and Pavement Marking of the National System of Interstate and Defense High-
ways. American Assn. of State Highway Officials (1961).

F-9. "Michigan Begins Study of Effectiveness of New Reflectorized Curve Markers." Hwy. Res. News No. 29, p. 9 (Autumn 1967).
F-10. "Adjustable Face Traffic Control Signal Head Standards." Tech. Report No. 1, Inst. of Traffic Eng. (revised 1966).
F-11. Manual of Uniform Traffic Control Devices for Streets and Highways. U.S. Dept. of Commerce, Bureau of Public Roads (June 1961).
F-12. Hoxie, J. P., "Color and Intensity Relationships in Traffic Signal." 31st Ann. Meeting Inst. of Traffic Eng. (1961).
F-13. Gazis, D., Herman, R., and Maradvoin, A., "The Problem of the Amber Signal Light in Traffic Flow." Operations Research, Vol. 8, No. 1, pp. 112-32 (Jan.-Feb. 1960).
F-14. Olson, P. L., and Rothery, R. W., Driver Response to the Amber Phase of Traffic Signals. (mimeo).
F-15. McLean, M. V., "About Instrumentation in General and Idiot Lights in Particular." Road and Track, Vol. 18, pp. 86-88 (1967).
F-16. Hugle, W., "How Microcircuits Will be Used in Automobiles." Electronic Products, Vol. 9, No. 10 (1967).

F-1\%. Gardner, A. R., "Special Reeport: Fiber Bundles Pipe Light Just Where You Want It." Product Eng., Vol. 38, No. 16 (1967).
F-18. "Fiber Optics." Design News, Vol. 22, No. 7 (1967).

F-19. Barrick, D. E., "Theory and Design of Longitudinal Control Systems for Automobiles." Eng. Experiment Station Report EE202-8, Ohio State Univ. (Dec. 1961).
F-20. "New Device Warns of Icy Bridge Decks." Maine Highway News, Vol. 10, No. 2 (1967).
F-21. "Automatic 'Icy Road' Sign Study." Report No. 0612, Colorado State Dept. of Highways, Planning and Research Div. (Aug. 1966).
F-22. "Developments to Watch." Product Eng., Vol. 38, No. 21 (1967).
F-23. Feasibility Study, New York State Safety Car Program: Final Report. Republic Aviation Div., Fairchild-Hiller, Farmingdale, N.Y. (1966).
F-24. Roeca, W. B., Todosiev, E. P., and Barbosa, L. C., "Development of an Electronic Highway Aid System." Eng. Experiment Station Report EE202-A-8, Ohio State Univ. (Sept. 1965).
F-25. Treiterer, J., and Rockwell, T. H., "Sensing and Communications Between Vehicles." NCHRP Report 51 (1968) 105 pp .
F-26. Jacobs, D., Fundamentals of Optical Engineering. McGraw-Hill (1943).
F-27. Pogust, F., Kuprijanow, A., and Forster, H., "Means of Locating and Communicating with Disabled Vehicles-Interim Report." NCHRP Report 6 (1964) 56 pp.

F-28. Reilly, R. and Parker, S., "Visual Information Related to Vehicle Control During Overtaking." Proc. Program Review Meeting, Research and Development of Traffic Systems, Bureau of Public Roads (1967).
F-29. Bauer, F., "An Integrated Vehicular Communications Systems Using the Ford Radio Alert." Paper No. 67011B, Soc. of Automotive Eng., Detroit (Jan. 1967).
F-30. Hanysz, E. A., "A Communication System for Driver Aid, Information and Routing." Paper No. 607111, Soc. of Automotive Eng., Detroit (Jan. 1967).

F-31. Gould, J., "Walkie-Talkie Bedlam." New York Times, February 12, 1967.
F-32. Doty, A., "Help for Motorists, A New Concept in Highway Safety." SAE Paper No. 650476 (May 1965).

F-33. "Detection Equipment-Rescue by Electronics." Product Eng., Vol. 36, No. 19 (1965).
F-34. "Tiny Transistor to Rescue." Design News, Vol. 22, No. 6 (1967).
F-35. "Communications with Stranded Motorists on California Urban Freeways." AIL Report No. 3097-1. Prepared for the State of Calif., Div. of Highways, Sacramento (Aug. 1967) (unpublished).
F-36. Covault, D. A., Dervish, T., and Kanen, A. C., "A Study of the Feasibility of Using Roadside Radio Communications for Traffic Control and Driver Information." Hwy. Res. Record No. 202 (1967) pp. 32-66.

F-37. Halstead, W., and Kelsey, G., "Highway Communications: A Review of Proposed Systems." Municipal Signal Eng. Spec. Report (Sept.-Oct. 1966).

F-38. Tamburri, T. N., and Theobold, D. J., Wrong Way Driving. Div. of Highways, State of Calif. (Feb. 1965).

F-39. "Electronics and Traffic Control." Proc. 28th Ann. Meeting, Inst. of Traffic Eng. (1958).
F-40. Wagner, L. C., and Harder, V. E., "Methods of Providing Information to Motorists on the Interstate System." Traffic Quarterly, Vol. 29, No. 4 (1965).

F-41. Kuprijanow, A., Rosenzweig, S., and Warskow, M. A., "Motorists' Needs and Services on Interstate Highways." NCHRP Report 64 (1969) 88 pp.
F-42. Emery, R. M., Grayum, J. Z., and Mammano, F. J., "A Technique of Highway Coding for Route Recognition and Position Description." Hwy. Res. Record No. 186 (1967) pp. 1-8.
F-43. Benedict, D. C., "MMD-Moving Map Display." Road and Track, Vol. 17, No. 11 (1966).
F-44. Study of the Safety Aspects of Holography on Highway Operations. Prepared by Forster Industries, Inc. for the Traffic Systems Division, BPR (1967).
F-45. Tompson, B. J. and Zinkey, W. R., "HolographyA Status Report." Research/Development, Vol. 18, No. 7 (1967).

F-46. Sullivan, W., "New Photo Technique Projects a World of 3-Dimensional Views." New York Times, March 19, 1967.<br>F-47. Fearing, B., "Breakthrough in Holography May Open Engineering Uses." Product Eng., Vol. 38, No. 3 (1967).

F-48. Kelsey, G. and Halstead, W., A Multi-Purpose Communications System for Highway Use. Paper presented before the Subcommittee on Communications, Audio Signs and Other Information Services for the Interstate Highway System of the American Assn. of State Highway Officials (Dec. 9, 1964).

## APPENDIX G

## CURRENT MAPPING PRACTICES*

The importance of map adequacy became apparent through two independent analyses. In the conduct of the study on current signing practices, 16 states were visited. In the majority of these states, it was stated that signs are oriented to the stranger with a map. Secondly, in the human factors task analysis, a field trip of about 800 miles was taken using maps as the only pretrip guide. The maps proved to be inadequate in many locations. It was then decided to interrogate formally each of the states about their mapping procedures. With the guidance and approval of the American Association of State Highway Officials (AASHO), a questionnaire was prepared and sent to each of the states, with a request for a copy of its official map. The returns were analyzed and the results are presented here. Figure G-1 shows a sample questionnaire.

To evaluate the usefulness of these maps, each map was studied in detail using the legend and the actual layout. Guidelines or standards had to be established to determine the amount of uniformity, helpfulness, and understanding that could be derived from the maps. The information from each state map was compared to the standards that are found in the recommendations in the Report on Uniform Map Symbols, issued by AASHO in 1962. Table G-1 gives the percentage of states that conformed to the AASHO standards (first column) and the percentage that was nonstandard. The third column, "Not Indicated," gives the percentage of states that did not show anything (nonstandard or standard) for certain information. In addition, a "Not Pertinent" percentage column is included that applies to information that was not applicable to some states. An example of this is the absence of the symbol or information for a ski area when looking at the State of Florida. Table G-2 gives additional percentage information on conformity in areas other than those found directly on the map or on the legend. It is assumed that these maps become more useful and understandable to the traveling public with a greater percentage of conformity to the standard, and a greater percentage of those standards indicated.

[^58]Information that was received was divided into the categories of highway and nonhighway symbols. Highway symbols are used on the maps to designate types of roads (two-lane paved, controlled-access, under construction, etc.) and types of highway markers (state highway, county highway, etc.). Nonhighway symbols indicate traveler services (points of interest, parks, airports, etc.).

In reference to highway symbols, various classes of roads and highways are depicted in the AASHO standard. Some of these, however, are not typical and cannot be found in some states. An analysis of conformance to standard indicated that 77 percent of the states conformed to the standard highway symbology.

After nonhighway symbols were evaluated it was found that there was 36 percent average conformity with the standard. The average percentage of the nonstandard is also low ( 18 percent), but this is not a true representation of the facts. It must be understood that a large percentage has been lost in the "Not Indicated" column, which also represents a loss to the standard percentage column figures.

In reviewing the area of emergency information such as first-aid stations, highway police, and state institutions, it was found that conformity to the standard was low (18, 16 , and 10 percent, respectively). The nonstandard was also low ( 0,19 , and 27 percent, respectively). What is pertinent is the "Not Indicated" column, which shows, for example, a 72 percent figure for first-aid stations. These emergency services should be indicated and conform to the standard to ensure quick responses.

It was found that in all areas of information that might be needed by the traveling public there was poor conformity to the standard. Commercial airports showed 39 percent nonstandard and 20 percent not indicated. Railroads showed 10 percent nonstandard and 37 percent not indicated. It was discovered that on the nonmap portion of the map more than 80 percent of the states included the major city detail inserts, which offers valuable assistance to the traveler. But, of the ten states with the largest populations, three did not include inserts of major cities.

## C- <br> CUTLERノHAMMER

AIRBORNE INSTRUMENTS LABORATORV AIRBORNE INSTRUMENTS LABORATORY

STATE:

QUESTIONNAIRE

1. DO YOU PUBLISH AN OFFICIAL HIGHWAY YES__ NO MAP OF YOUR STATE, AVAILABLE TO
THE GENERAL PUBLIC?
(IF YES, PLEASE SEND A COPY.)
2. DO YOU PUBLISH ANY SPECIALIZED YES__ NO__

MAPS (METROPOLITAN AREA, EXPRESS-
WAY, ETC.) USED FOR ORIENTATION OR
TRIP PLANNNG BY THE GENERAL PUBLIC?
(IF YES, PLEASE SEND COPIES.)
3. HOW IS THE MAP DISTRIBUTED?

BY REQUEST $\qquad$
AVAILABLE AT OFFICLAL AGENCIES
THROUGH PRIVATE PARTIES--MOTELS
GAS STATION
OTHERS (SPECIFY) $\qquad$
4. IS MAP DISTRIBUTED FREE OF CHARGE? YES ___ NO
5. HOW IS THE EXISTENCE OF THE MAP

PUBLICIZED?
WORD OF MOUTH $\qquad$
NEWS RELEASE $\qquad$
OTHERS (SPECIFY)
NONE $\qquad$
HOW MANY ARE DISTRIBUTED ANNUALLY? $\qquad$
7. HOW OFTEN IS THE MAP (OR MAPS) UPDATED?

YEARLY
MORE OFTEN
LESS OFTEN
8. WHO HAS THE PRIMARY RESPONSIBILITY FOR EDITING?

HIGHWAY DEPARTMENT
OTHER STATE AGENCIES
PRIVATE MAP COMPANES
9. WHICH COMPANY PRINTS YOUR MAP?
10. IS IT POSSIBLE FOR A MOTORIST PLANNING A TRIP TO PREDICT FROM THE MAP WHICH TOWN NAMES ARE USED FOR DESTINATION SIGNING BY THE HIGHWAY DEPARTMENT?

COLOR $\qquad$
SIZE
UNDERLINE $\qquad$
TYPE FACE $\qquad$
OTHER (SPECIFY) $\qquad$
NONE $\qquad$
11. WHAT OTHER AGENCY OR AGFNCIES IN YOUR STATE (PRIVATE OR PUBLIC) EXCEPT OIL COMPANIES AND MOTOR
CLUBS SPONSOR, PUBLISH OR DISTRIBUTE TO THE GENERAL PUBLIC STATEWIDE OR SPECIALIZED HIGHWAY MAPS WHICH MAY BE USED FOR TRIP PLANNING AND ORIENTATION?
$\qquad$
$\qquad$
$\qquad$

Figure G-1. Sample questionnaire.
12. WHAT SUGGESTIONS DO YOU HAVE TO IMPROVE MAPS TO MAKE THEM MORE USEFUL TO MOTORISTS IN PLANNING THEIR TRIPS?

13
 DION OF THE 1962 AASHO 'RE PORT ON TION OF THE 1962 AASHO " H
UNFORM MAP SYMBOLS'?
(B) DO YOU THINK IT WOULD BE DESIRAABLE TO HAVE A SIMILAR SET OF UNIFORM STANDARDS FOR STATE HIGHWAYS MAPS COVERING SUCH ASPECTS AS SCALE, TYPE OF INFORMATION, ETC.?
(C) IF YES, WHO SHOULD GENERATE THESE STANDARDS?
AASHO $\qquad$
AAA $\qquad$
COAST AND GEODETIC SURVEY $\qquad$
NATIONAL GEOGRAPHIC SOCIETY $\qquad$ OTHER
14. IN WHAT FORM, AND HOW FREQUENTLY, IS INFORMATION ON DETOURS AND CONSTRUCTION ACTIVITIES DISTRIBUTED?
$\qquad$
$\qquad$
15. DO YOU WANT TO MAKE ANY ADDITIONAL COMMENTS:
$\qquad$
$\qquad$
$\qquad$
$\qquad$

SIGNED $\qquad$
TITLE $\qquad$

Information pertaining to overnight tourist facilities, restaurants, and refreshment areas is not given on any of the state maps. If this information were available to the public, it might be of great help in trip planning, daily planning, and excursions. Another type of service not shown on state maps is the location of auto service centers, often necessary for unexpected circumstances.

In the over-all analysis of state maps, it was found that some states used map symbols that did not appear on the legends, and other states used the standard symbols for meanings other than the recommended meanings.

In connection with this study, a questionnaire was sent to each of the 50 states inquiring as to some of the practices involved in the publication and distribution of the official state highway maps. They were also asked for suggestions, and asked if they were following the recommendation of the 1962 AASHO Report on Uniform Map Symbols.

It was found that all of the states but one presently publish official maps that are distributed free of charge to the public. Most states distribute their maps through the media of official agencies, motels, and gas stations. Annual distribution runs from a low of 100,000 to a high of 2.5 million, with more than 80 percent of the states updating yearly. None of the state maps indicated which town names were used for destination signing.

- Of the-states-responding, 57 percent gave suggestionsto improve maps to make them more useful to motorists in planning trips. Suggestions ranged from the complete use of uniform symbols and the adoption of AASHO standard map symbols, to keeping up-to-date, uncluttered, , and better descriptions of points of interest. A sizable percentage commented that it would be advisable to show portions of adjacent states on their maps.- This was-found to be the practice in more than 90 percent of the maps.

In response to the question, "Do you follow the recommendation of the 1962 AASHO Report on Uniform Map Symbols?" about 82 percent of the states answered "yes." Of these "yes" replies, four also stated "partly," one "generally," and one "where applicable." Of the percentage that checked "no," one stated "used recommendation as a guide," and two stated "only used partially." Although 82 percent reported that they did conform, actual map investigation shows that an average of only 36 percent conform to the method of indicating nonhighway symbols and 77 percent conform in indicating highway symbols.
In addition, 55 percent answered "yes" to the question, "Do you think it would be desirable to have a similar set of uniform standards for state highway maps covering such aspects as scale, type of information, etc.?," and more than 55 percent indicated that AASHO should generate these standards. The information received through the questionnaire shows that the majority of states feel that the use of standard nonhighway symbols will assist the public in all areas of travel services. Of extreme importance is the fact that a large percentage of states not conforming to the standard have indicated that they are in the process of converting to the standards.

In evaluating the usefulness of state highway maps, other nonmap information that might be given to aid the traveler

TABLE G-1
STATE MAP INCLUSIONS

| ITEM | CONFORMANCE TO AASHO STANDARDS (\%) |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | $\begin{aligned} & \text { STAN- } \\ & \text { DARD } \end{aligned}$ | NON-STANDARD | NOT <br> INDI- <br> CATED | NOT <br> PERTI- <br> NENT |
| State parks and memorials | 45 | 43 | 12 | 0 |
| Campsites | 31 | 28 | 41 | 0 |
| Game reserves | 8 | 23 | 69 | 0 |
| Fish hatcheries | 33 | 11 | 55 | 1 |
| Ranger stations | 6 | 18 | 76 | 0 |
| Reservations (Indian/other) | 19 | 20 | 45 | 16 |
| Points of interest | 45 | 37 | 18 | 0 |
| Roadside parks | 37 | 39 | 24 | 0 |
| First-aid stations | 18 | 0 | 72 | 0 |
| Public boat access | 8 | 8 | 61 | 23 |
| Ski areas | 6 | 18 | 27 | 49 |
| Colleges and universities | 14 | 33 | 53 | 0 |
| State institutions | 10 | 27 | 63 | 0 |
| National forests | 55 | 23 | 12 | 10 |
| Population symbols | 65 | 27 | 8 | 0 |
| County seat/capital | 76 | 18 | 6 | 0 |
| Time boundary | 16 | 4 | 6 | 74 |
| National boundary | 20 | 13 | 2 | 65 |
| State boundary | 86 | 10 | 2 | 2 |
| County boundary | 55 | 37 | 8 | 0 |
| Railroads | 53 | 10 | 37 | 0 |
| Airports (commercial) | 41 | 39 | 20 | 0 |
| (military) | 24 | 49 | 27 | 0 |
| (other/private) | 31 | 43 | 26 | 0 |
| Local mileage (between cities) | 94 | 4 | 2 | 0 |
| Consolidated mileage (between major points) - | 80 | 2 | 18 | 0 |
| Bridges (toll) | 55 | 2 | 8 | 35 |
| (free) | 53 | 2 | 8 | 37 |
| Ferry (toll) | 51 | 2 | 8 | 39 |
| (free) | 49 | 2 | 8 | 41 |
| Highway police | 16 | 10 | 74 | 0 |
| Elevations | 45 | 2 | 53 | 0 |
| Ports of entry | 25 | 6 | 63 | 6 |
| Springs/wells | 6 | 0 | 94 | 0 |
| Lighthouses | 4 | 18 | 37 | 41 |
| Markers (historical) | 10 | 43 | 47 | 0 |
| Trails (historical) | 21 | 8 | 71 | 0 |
| Average | 36 | 18 | 34 | 12 |

TABLE G-2
OTHER THAN STATE MAP INCLUSIONS

| OTHER THAN STATE MAP INCLUSIONS |  |
| :--- | :--- |
|  | CONFORMITY |
| TO AASHO |  |
| ITEM | STANDARDS |
| City detail inserts | $(\%)$ |
| Pictorial inserts | 83.7 |
| Description (points of interest) | 79.6 |
| States events calendar | 44.9 |
| Mileage scale (linear) | 4.1 |
| Mileage between principal cities | 100.0 |
| Alphanumeric coordinate references | 81.6 |
| Geographical coordinate references | 87.8 |
| Detail information state/national parks | 51.0 |
| Relief pictorial | 51.0 |
| Overlap of adjacent states | 24.5 |

has been considered. A few of the following possibilities have been found on some of the state maps, but the percentage did not warrant a separate listing:

1. A listing of state laws pertinent to highway safety, which may include such facts as the explanation of trafficlight signals and principal arterial highway inserts.
2. A periodical road condition map.
3. An insert of the major U.S. highway system.

In relation to the last material presented, questions about the amount of space and additional cost could be raised. As to space, it was found that 31 percent used all the space on the reverse side plus the additional space around the map itself for state facilities and "points of interest" ad-
vertising; 16 percent used 75 percent of the space for their advertising and 16 percent used 50 percent; 25 percent used 25 percent or less space, whereas only 12 percent used this space for other informational services. Pictures of points of interest and state facilities are of interest to the traveler but should be allotted less space. Inclusion of more nonmap material would cost more, but this additional cost could be compensated for by reducing the present number of full-color pictures.

The question is whether the public is now receiving enough information of a clear nature. It is evident through the material presented that there is a definite need for additional aids and clarity in the marking of maps to increase the understanding of the traveling public.

## APPENDIX H

# NOTES FOR A MANUAL ON INFORMATION SYSTEM REVIEW PROCEDURES * 

## INTRODUCTION

In the course of the research, a determination was made of the information needs of the highway user and the way in which they are presently being satisfied. Emphasis was placed on human factors considerations involved in designing an information system that satisfies the needs of the highway user. These findings are discussed in Part I.

An apparent conclusion is that a considerable gap exists between sound human factors principles and highway information system designs presently in service.

A portion of the difficulty can be attributed to inadequate roads and poor geometric designs. In these cases, application of sound user-centered information system designs will help in making these roads safer and more convenient to the user. However, the cause of the difficulty must be recognized as being attributable to the road itself, and the only practical solution is redesign.

There are, however, new, properly designed roads where the information systems do not satisfy the information needs of the user. Here problems are primarily associated with inadequate and/or poorly designed information systems that do not take into account the characteristics and needs of the user. The causes of this situation stem from several factors. These include (1) time and budgetary pressures placed on designers and reviewers, (2) a lack of understanding of important human factors principles, (3) local requirements that force the designer to incorporate faulty or questionable information designs, and (4) rigid adherence to manuals that may be inadequate for the situation.

[^59]The purpose of this section is to bridge the gap between major human factors principles and the design and review of highway information systems. To this end, the human factors principles and findings have been incorporated into the following information system review manual.

Because the manual is preliminary, it is titled "Notes for a Manual on Information System Review Procedures." The form of the manual is fluid and contains recommendations of what the researchers consider to be a workable procedure.

The manual is meant to stand by itself.: Furthermore, it is structured to be a tool for the review of information system designs, rather than an aid to the development of such designs. The manual is designed to help the reviewer identify and rectify potential information system deficiencies in the design stage. In addition, the manual is designed to retain the many good features of present information system design practices.

The manual has not been extensively field-tested. It is expected that its use by operating and design engineers will result in procedural simplification. It is also expected that each jurisdiction and agency that chooses to adopt the manual as an operating tool will tailor it to its own specific requirements and procedures.

The human factor principles, discussed fully in Part I of this report, are the keystone on which any information system designed to assist drivers in the safe, expeditious, convenient, and comfortable accomplishment of their driving task must be based.

[^60]
## PURPOSE AND SCOPE

The purpose of this manual is to provide reviewers with a tool to assist them in evaluating information system designs, and to ensure that important highway-user related factors are considered.

The manual will also assist the reviewer in recognizing potential information system design problems and in formulating solutions.

The scope of this manual is limited to the following:

1. Specifically applicable to Interstate and Interstatetype highway configurations. However, the principles enumerated herein are equally applicable to all highways, and the procedures can be modified to accommodate all highway types.
2. Applicable to aspects of highway information systems related to markings, delineations, and signs.
3. Applicable to cases covered by (1) The American Association of State Highway Officials' Manual for Signing and Pavement Marking of the National System of Interstate and Defense Highways (1961 ed.), and (2) the Manual of Uniform Traffic Control Devices for Streets and Highways (w/Amendments), U.S. Department of Commerce, Bureau of Public Roads (June 1961).

## CHAPTER ONE: DESIGN REVIEW PROCEDURE

Many highway and traffic engineers review signing plans. A procedure has been developed to aid these personnel in their checking and reviewing activities and to provide a rapid means of ensuring that the design takes into account sound human factors engineering principles. This procedure is meant to serve as a review tool rather than as the basis for initiating new designs.

The procedure was formulated on the basis of interviews and conversations with working personnel in state highway departments and the Bureau of Public Roads. There were many differences noted in reviewing assignments, reviewing practices, administrative procedures, signing plan details, and materials. The procedure has therefore been constructed to accommodate most of these differences. However, it is recommended that a uniform set of consistent procedure and practices be adopted nationwide.

## DRIVING TASK DESCRIPTION

There are three essential driving elements: control, guidance, and navigation. Control includes vehicle operation tasks such as starting, stopping, speed control, and steering. Guidance tasks are directed toward maneuvering the vehicle on the road in response to roadway elements, traffic, environmental factors, legal requirements, etc. Navigation encompasses direction finding and route following tasks.

Drivers search the environment for information to satisfy their information needs. For the control tasks, the driver obtains information relative to vehicle operation and keeping his vehicle in motion on the road. Because vehicle control must be maintained throughout,
the driver must always have this information at his disposal. For guidance, the driver is involved primarily with maintaining a safe and efficient course in relation to events on the roadway. Because these events do not necessarily occur continuously, the driver needs guidance information about events that will effect his safe and efficient course of travel in sufficient time to make necessary vehicle control adjustments. For navigation tasks, the driver is following a trip plan from his origin to his destination by obtaining information as to where he is, and where he is going.

## PURPOSE OF THE HIGHWAY INFORMATION SYSTEM

There exists a body of information needs associated with each of the basic elements of the driving task. The purpose of the highway information system is to satisfy these needs by providing the driver with the information he needs, when he needs it, and in the form that he can best use it.

Table H-1 gives common information needs of the driver.

The highway information system cannot satisfy all driver information needs. A reviewer should be aware of those information needs that can be satisfied. The reviewer should also recognize that because the present information system cannot satisfy certain information needs does not mean that the driver does not require or

TABLE H-1
TYPICAL INFORMATION NEEDS

| TYPE | NEED |
| :---: | :---: |
| Control-related | Vehicle handling characteristics |
|  | Vehicle operating conditions |
|  | Lateral location |
|  | Longitudinal location |
|  | Speed |
|  | Acceleration |
|  | Horizontal alignment |
|  | Vertical alignment |
|  | Cross section (lanes, medians, shoulders) |
| Guidance-related | Climatological conditions |
|  | Surface conditions |
|  | Horizontal alignments (changes in) |
|  | Vertical alignments (changes in) |
|  | Cross section (changes in) |
|  | Obstacles-on/off road |
|  | Special features (all) |
|  | Traffic features |
|  | All regulatory (legal requirements) |
|  | Interchange features (geometric and traffic) |
| Navigational-related | Available services (including emergency) |
|  | Directions to destinations |
|  | Distance to destination |
|  | Designation of road (name, type) |
|  | Direction of road |
|  | Designation of interchange |
|  | Designation of destination |
|  | Potential destinations from interchange |

receive this information. Thus, information displayed via the formal (i.e., signs and marking) highway information system forms only a portion of the driver information sources, with information also being received via informal sources.

## INFORMATION NEEDS SATISFIED BY THE PRESENT HIGHWAY INFORMATION SYSTEM

Table H-2 indicates those information needs that are satisfied by the present formal information system, and the way in which they are satisfied. The table indicates that only a portion of the information needs can be satisfied by standard treatments presented in manuals, and, in certain cases, only by inference. These represent the formal information system displays covered by the design review procedure.

Because the repertoire of the present highway information system is limited, the reviewer may suggest or approve non-manual information display in extreme cases. However, this course of action should be used only as a last resort, and never when a standard treatment is usable and applicable.

## REVIEW MATERIAL

The following documents are required to use the design review procedure: signing plans for the highway; readily available road maps of the area; and applicable signing manuals. The following additional material should also be obtained by the reviewer: highway construction plans, or equivalent, and traffic data. Finally, in the course of the review activity, a field trip to the site is advisable and is recommended.

## PRELIMINARY DETERMINATIONS

The first step in the design review procedure is to make several preliminary determinations. Although ten categories are listed in the following, the reviewer is not required to perform a major evaluation and analysis. In most cases the information should be readily available, and the reviewer should not spend too much time on this phase. However, if the reviewer suspects a major problem associated with any aspect of the preliminary determinations, a more detailed evaluation would prove useful.

## Definition of the Section to be Reviewed

Among the aspects of the highway section to be defined are the following.

## Nature of the Section

The reviewer should determine whether the section is a complete stretch of roadway or a partial section. If it is a partial section, it should be determined whether it is a continuation of an existing road or an entirely new section. The purpose of making this determination is to ensure that the principle of continuity * is adhered to.

[^61]Therefore, if the reviewer finds that the stretch of highway being reviewed is a continuation of an existing road he should familiarize himself with the information system and display techniques employed on the existing stretch. This may be accomplished by referring to the existing signing plans or by a field trip.

## Class of Road

The reviewer should determine what class of road (e.g., Interstate, Interstate type, parkway) is being reviewed.

## Length of Section

The next determination to be made is the length of the stretch of road being reviewed. If the stretch of road is long and somewhat complex, the reviewer might find it easier to review the signing plans for the highway in segments rather than as a complete section. In many instances, the nature of the plans will determine whether the review is to be continuous or segmented. If the review is segmented, the segments reviewed must be "overlapped" so that no discontinuities in information display occur. In addition, the reviewer must be aware that the information display for one segment may appear in a preceding segment.

The reviewer should choose his segments logically, preferably separating them in steady-state areas so as to minimize his difficulty in putting the segments together.

## Design Speed

The design speed of the highway should be specified. The reviewer can determine this from the construction plans. If posted speed will differ from design speed, this should be noted.

## Design Traffic Volume

The design traffic volume for the highway should be specified.

## Design Type

The type of design (i.e., final or stage) should be determined. As presently conceived, the sign review procedure is applicable both to existing highway information systems and new designs. However, emphasis in the application of the procedure is on new design. The reviewer should recognize that stage construction poses a more difficult review task than final design, owing to the temporary nature of some signs and the high probability of change before the final design. A stage review should be subsequently re-reviewed when the final design is made.

## Major Changes

When reviewing any new design, but especially a stage design, the reviewer should determine if there will be any major changes that can be predicted. For example, are major new traffic generators (shopping centers, parks, stadiums, etc.) being contemplated? Will new interchanges be added or will exits be closed? The reviewer should be able to obtain this information from the planning office.

TABLE H-2
INFORMATION NEEDS SATISFIED BY PRESENT INFORMATION CARRIERS ${ }^{\text {a }}$

| INFORMATION NEED | MANUAL TREATMENTS | satisfaction |
| :---: | :---: | :---: |
| (a) Control-related |  |  |
| Lateral location | Pavement markings Delineators | Direct Direct |
| Longitudinal location | Pavement markings <br> Delineators | Direct Direct |
| Horizontal alignment | Pavement markings Delineators turns and curves signs ADVISORY SPEED signs | Direct <br> Direct <br> Direct Inferential |
| Vertical alignment | truck climbing lane signs hill signs USE LOW GEAR signs | Inferential Direct Inferential |
| Cross section | Pavement markings | Direct |
| (b) Guidance-related |  |  |
| Climatological conditions | Slippery when wer signs | Inferential |
| Surface conditions | BUMP or dip signs | Direct |
| Horizontal alignment (change in) | Pavement markings Delineators TURNS and Curves signs ADVISORY SPEED signs | Direct <br> Direct <br> Direct <br> Inferential |
| Vertical alignment (changes in) | truck climbing lane signs hill signs use low gear signs | Inferential Inferential Inferential |
| Cross section (change in) | Pavement width transition signs | Direct |
|  | ONE LANE bridge signs | Direct |
|  | road narrows signs | Direct |
|  | truck lane signs | Direct |
|  | divided highway signs | Direct |
|  | lane closed signs | Direct |
|  | Single lane signs | Direct |
| Obstacles off/on road | SOFT SHOULDER signs | Direct |
|  | low clearance signs | Direct |
|  | Zebra striping and object markings | Direct |
|  | narrow bridge signs | Direct |
| Special features | road Closed signs | Direct |
|  | narrow bridge signs | Direct |
|  | Pavement ends signs | Direct |
|  | sChOOL and SCHOOL Crossing signs | Direct |
|  | rr crossing signs | Direct |
|  | double arrow signs | Direct |
|  | detour signs | Direct |
|  | All construction and maintenance signs | Direct |
|  | toll booth signs | Direct |
| Traffic features | stop signs | Inferential |
|  | Yield signs | Inferential |
|  | one way signs | Inferential |
|  | two way traffic ahead signs | Direct |
|  | end one way signs | Inferential |
|  | Stop ahead signs | Inferential |
|  | Signal ahead signs. | Inferential |
|  | merging traffic signs | Inferential |
|  | divided highway signs | Inferential |
|  | All crossing signs | Inferential |
| Legal and regulatory | stop signs yield signs | Direct Direct |

TABLE H-2 (Continued)

| INFORMATION NEED | Manual treatments | satis- <br> faction |
| :---: | :---: | :---: |
| Interchange features | All speed limit signs | Direct |
|  | All turn prohibited signs | Direct |
|  | All lane-use control signs | Direct |
|  | do NOT Pass and pass with care signs | Direct |
|  | SLOWER TRAFFIC KEEP RIGHT signs | Direct |
|  | TRUCK USE Signs | Direct |
|  | KeEp right signs | Direct |
|  | DO NOT ENTER signs | Direct |
|  | One way signs | Direct |
|  | Parking and stopping signs | Direct |
|  | KEEP OFF MEDIAN signs | Direct |
|  | weight limit signs | Direct |
|  | Pavement markings | Direct |
|  | Traffic lights | Direct |
|  | stop signs | Inferential |
|  | yield signs | Inferential |
|  | Cross road and side road signs | Direct |
|  | T symbol and y symbol signs | Direct |
|  | Stop ahead signs | Inferential |
|  | Yield ahead sign | Inferential |
|  | merging traffic signs | Inferential |
|  | All crossing signs | Direct |
|  | Junction markers | Inferential |
|  | Advance turn and directional arrow signs | Inferential |
|  | Gore exit signs | Direct |
|  | Exit directional signs | Direct |
|  | Advance signs | Inferential |
|  | Parking area signs | Direct |
|  | Pavement markings | Direct |
| (c) Navigational-related |  |  |
| Available services | All service signs | Direct |
| Directions to destination | trailblazers | Direct |
|  | advance turn arrows | Direct |
|  | ROUTE TURN assemblies | Direct |
|  | directional arrows and assemblies | Direct |
|  | Temporary, alternate, business route markers | Direct |
|  | Detour arrow signs | Direct |
|  | distance signs | Direct |
|  | advance exit signs | Direct |
|  | next Exit signs | Direct |
|  | Mileposts | Inferential |
| Designations of roads: Destination | Route markers | Direct |
|  | COMBINED Junction signs | Direct |
| Interchanges | directional assemblies | Direct |
| Potential destinations | trailblazers | Direct |
|  | Street name signs | Direct |
|  | EXIT direction signs | Direct |
|  | Exit advance signs | Direct |
|  | destination and distance signs | Direct |
|  | Information area signs | Direct |
| Direction of road | CARDINAL DIRECTION marking | Direct |
|  | route markers | Direct |
|  | Exit direction signs | Direct |
|  | Advance exit signs | Direct |

If major changes are expected, the reviewer should consider the information system in this context and note future information needs and potential problem locations.

## Abutting Land Use and Service Availability

The abutting land use of the highway section should be determined. This can be determined on the basis of inspection of aerial photographs, from a field survey, or from general knowledge of the area. The reviewer should know if the abutting land is rural, urban, business, or a mix.

In addition, the reviewer should determine availability of services adjacent to the highway right-of-way and note their type and location.

## Jurisdiction

The reviewer must determine the highway jurisdiction, and what legal and administrative constraints exist. A determination should be made of whether there is a change in jurisdiction within the section being reviewed.

## Manual Applicability

The reviewer should specify the applicability of the marking and signing manuals. The procedure is based on the AASHO Interstate Manual and the BPR manual, Uniform Traffic Control Devices for Streets and Highways. However, there may be instances when these manuals are supplemented by manuals issued by state and local jurisdictions. In these cases, the reviewer should determine if any conflicts in manual applicability exist. If conflicts exist, they should be resolved prior to the application of the review procedure.

## Traffic Information

If traffic data are available, the reviewer should obtain whatever exist for the highway section, such as ADT, DHV, and O\&D data. From this, he can begin to develop inputs relative to potential traffic-related problem locations and likely guide sign destinations.

## Ambient Conditions

The reviewer should specify ambient lighting and climatological conditions for the highway section for which the sign review is to be accomplished. The bearing of the road should be considered and a determination should be made of possible adverse sun conditions.

A determination should be made of possible adverse ambient conditions (heavy snow, fog, icing, etc.). In the case of heavy snow, a determination of the snow-removal practices should be made as it has a direct bearing on pavement-marking effectiveness.

## Discontinuities

A determination to be made is whether, and what discontinuities exist in any of the aspects discussed previously. If discontinuities exist, the reviewer should note them for further evaluation and should decide whether the review should be segmented because of the discontinuity. Examples of common discontinuities include changes in traffic demand or composition, changes in
jurisdiction, changes from rural to urban abutting land use, and changes from lighted to unlighted sections. Climatological changes within a section are relatively uncommon, except for potential fog locations.

## User Characteristics

The reviewer should consider potential road-user characteristics and determine if there are any special attributes that must be considered. These include:

1. Elderly drivers-found in retirement areas.
2. Non-English-speaking drivers-found in border areas (Mexico, Canada) and where large, non-English populations cluster (e.g., Florida, New York).
3. Illiterate drivers-found in some rural areas.
4. Large transient populations-found on major through routes and in or near popular resort areas or tourist attractions.

## IDENTIFICATION OF POTENTIAL PROBLEM LOCATIONS

The next step is an identification of potential information system problem areas and locations. Here, the reviewer, working primarily with signing and construction plans, analyzes the highway section and notes locations and areas that require detailed evaluation because of their problem potential.

In subsequent steps, the information system for the entire section is reviewed, with the noted problem areas and locations further analyzed. First, the markings and delineation, warning and regulatory, and guide and service signing aspects are considered separately. Following this, the total display of information is evaluated, and a determination is made as to the suitability of the full information presentation at the problem locations.

Problem areas and locations are determined by analyzing the signing and construction plans and noting steady-state and special-feature areas and locations. It is recommended that the reviewer note special-feature and steady-state areas directly onto the plans.

Special-feature areas and locations are where the majority of information system problems may occur. However, there may also be problems (e.g., vigilance) in steady-state areas. The reviewer can refer to "straight-line diagrams" (or equivalent) and note interchange spacing to obtain an indication of potential vigilance problems. In conjunction with this, the reviewer can refer to the preliminary abutting land-use determinations.

From the nature of the road and the abutting land use determination the reviewer usually can gauge what problems may exist. For urban Interstate routes, problems usually are associated with high-signal areas and many special features, whereas on rural roads, problems are more likely to be in low attention demands with their associated vigilance problems and unexpected, although usually rare, special-feature areas.

Although the reviewer can look at both sides of the road when reviewing the plans for potential problems, it is recommended that he analyze the plans in one direction before going to the other direction.

## Identification of Steady-State Locations

Steady-state areas and locations are defined as areas and locations where the driver's task involves only "simple" steering and speed control maneuvers and "easy" decisions (i.e., where there is no likelihood of his being "overloaded" because of complex or unexpected events on the road). The reviewer can consider a steady-state area or location as being those portions of the road that are not specialfeature areas or locations.

To qualify as a steady-state area, the following conditions must be met:

1. Main-Line Location-Steady-state areas always located on the main line of the highway. (Off-line areas of the highway are not covered by this analysis except in the case of interchange ramps.)
2. Lanes-The highway must have a minimum of two lanes and a maximum of four lanes in each direction.
3. Median-A steady-state area, by definition, has a median at least 8 ft wide dividing the two directions of travel.
4. Shoulders-A steady-state area has a right-hand shoulder at least 8 ft wide.
5. Obstructions off the Traveled Way-To qualify as a steady-state area, there should be no obstructions off the traveled way such as abutments, and bridges.
6. Alignment-There should be no extremes in horizontal or vertical alignment. To qualify as an extreme in horizontal alignment, the curve would exceed the $5^{\circ}$ curvature specified in Interstate practices. With regard to vertical alignment, any grade in excess of 5 percent is extreme. (Flatter grades may qualify as an extreme if their length is such to affect the speed of truck traffic.) In most instances, it is highly unlikely that extremes in alignment will be found on Interstate and Interstate-type roadways.

To qualify as a steady-state area, there must be no major restriction of sight-lines. Usually, this can be determined on the basis of an inspection of construction plans. However, there are instances when the line of sight falls outside the right-of-way where this may not be possible. In those cases, a field trip to the site is required.

The preliminary determination may also identify what appears from an inspection of the signing plans to be a steady-state area is actually not the case. For example, a determination of heavy fog conditions may make a steadystate area a special-feature area. Similarly a very heavy traffic situation may make a steady-state area a specialfeature area.

Identifying a steady-state area does not mean that driver decisions will not be made in the steady-state area for events and features downstream. However, the steadystate location is a likely candidate for the best area to provide the driver with information to perform an upcoming maneuver and/or make a complex decision (see "Spreading").

## Identification of Special-Feature Locations

One of the most important steps in the design review procedure is the identification of special-feature locations
and areas. Special-feature locations can take the form of any of the following, either singly or in combination:

1. Standard interchanges.
2. Unusual interchanges.
3. Extremes in roadway geometrics.
4. Unusual maneuvers.
5. Changes in cross section.
6. Off-line restrictions.
7. Sight-line restrictions.
8. Environmental consequences.
9. Miscellaneous features.
10. Heavy traffic.
11. High-signal areas.

There are several ways in which the reviewer can proceed in reviewing the signing and roadway plans and identifying special-feature areas or locations. He may find it more convenient to evaluate the plans in terms of each type of special-feature area (i.e., he may first identify all interchanges, then proceed to identify all extremes in geometrics, etc.). Although the way in which the reviewer actually accomplishes the identification is a matter of expediency and personal preference, the recommended procedure is to start furthest downstream and work backward, noting the special feature on the plans. In this way the reviewer can evaluate what the driver may be doing prior to the special-feature location and area. This method of approach is recommended for all aspects of the review procedure.

## Standard Interchanges

For purposes of the design review procedure, all interchanges are considered to be special features. The reviewer should recognize that a majority of the problems will be associated with exits and entrances. However, it should also be kept in mind that some exit and entrance configurations will pose more problems than others. Accordingly, Interchanges have been dichotomized in terms of standard and unusual. In most instances, the standard interchanges' major information display problem will be associated with the guide signing required. In the case of the unusual interchange, there may be more critical problems.
The reviewer must classify each interchange in terms of standard or unusual and, if it is determined to be unusual, identify potential information display problems that may be associated with the unusual aspect of the interchange.

Because the design review procedure is applicable to Interstate and Interstate-type routes, the only interchanges discussed are controlled access. That is, there is no consideration of at-grade crossings (either highway or railroad) or uncontrolled-access exits or entrances in the procedure. If these occur, they are to be considered unusual.

In evaluating the interchanges on the road, the reviewer should evaluate exits and entrances separately.

Exits.-To be classified as a standard exit, the exit should be:

1. Located on a tangent section.
2. A single-lane, right-hand off-ramp.
3. A deceleration lane, either tapered or parallel, of adequate length.

In addition, the deceleration lane should be such as to create no path confusion and should not appear as a lane addition.

To be considered a standard exit ramp, there should be no extremes in geometrics, no unusual maneuvers, only one direction of traffic, and no violation of expectancies at the terminus of the ramp (e.g., traffic control, difficult merges). Thus, the interchange and associated ramps could be any of the following:

1. Standard cloverleaf.
2. Parclo.
3. Standard diamond.
4. Split diamond.

Entrances.-To be classified as standard, the entrance should be:

1. Located along a tangent section.

TABLE H-3
UNUSUAL INTERCHANGE DESIGN FEATURES

| class | DESIGN FEATURE |
| :---: | :---: |
| Exits | Bifurcation |
|  | Double exit |
|  | Exit on horizontal curve (or combined horizontal/vertical) |
|  | Exit on vertical curve (or combined horizontal/vertical |
|  | Lane drop at exit |
|  | Left exit |
|  | Missing or short exit deceleration lane |
|  | Tangent off-ramp |
|  | Two (or more)-lane exit |
|  | Exit to collector-distributor road |
|  | Unusual ramp and/or ramp terminus features |
| Entrances | Double entrance |
|  | Entrance on horizontal curve (or combined horizontal/vertical) |
|  | Entrance on vertical curve (or combined horizontal/vertical) |
|  | Lane addition at exit |
|  | Left entrance |
|  | Missing or short acceleration lane |
|  | Two (or more)-lane entrance |
|  | Unusual ramp geometrics |
|  | Metered ramps |
|  | Extremely high-volume entrances |
| Exits/Entrances | Multilevel exit/entrance |
|  | Common acceleration/deceleration lane |
|  | Inadequate weaving areas |
| Miscellaneous | At-grade crossing |
|  | Restricted interchanges (by type of traffic or by time of day) |
|  | Uncontrolled access |
|  | Very long interchange spacing |
|  | Very short interchange spacing |

2. A single-lane, right-hand on-ramp.
3. An adequate acceleration lane (either parallel or tapered).

In addition, the transition from the acceleration lane should pose no path confusion to either the driver taking the entrance or to the main-line driver, nor should it appear as a lane addition.

## Unusual Interchanges

By definition, all interchanges not classified as standard are unusual. If the reviewer determines that an exit or entrance is unusual he should identify its unusual characteristics.

Some of the more common unusual interchange features are given in Table H-3. The implications of these features are discussed subsequently. The procedure is not meant to supplant the reviewer's engineering judgment but rather to assist him. Therefore, the reviewer is expected to apply judgment in identifying unusual interchanges and evaluating their impact. Thus, Table H-3 and the ensuing discussion are presented to structure the reviewer's thinking and aid him in the application of engineering judgment. (The engineering judgment remarks are applicable to all aspects of the procedure.)

## Extremes in Roadway Geometrics

Extremes in roadway geometrics should be a relatively rare occurrence on new Interstate and Interstate-type roadways. The experienced reviewer should have no difficulty in identifying extreme horizontal and vertical alignments and should be able to quickly pick these out from signing and construction plans.

Extreme geometrics may generate driver problems involving vehicle control difficulty. For example, a steep hill would require trucks to use lower gears. In addition, if there are adverse climatological conditions, such as ice and snow, extremes in geometrics may contribute to skidding.

The reviewer should note that extreme geometric configurations will usually be accompanied with restrictions in sight lines, especially at crests and on sharp curves.

## Unusual Maneuvers

When evaluating plans for unusual maneuvers, the reviewer must consider two aspects: unusual maneuvers required of the driver, and unusual maneuvers by other vehicles.

A way in which this can be determined is by "finger driving" the road. In the unusual maneuvers by the driver, the reviewer should trace the plans as if he were a main-line driver. Starting as far upstream as the plans cover, and starting in the right-hand lane, the reviewer should trace the path that the driver must follow to remain on the main line to the furthest point downstream. This procedure should be repeated for each lane. (Any area with more than four lanes, or less than two lanes, is to be treated as a special feature.) The reviewer should determine and note if a driver will be required to perform an
unusual maneuver such as weaving across several lanes of traffic (as in the case of a major bifurcation) to remain on the main line.

After the reviewer has determined whether a driver is required to perform an unusual maneuver (from any main-line lane) to remain on the road, the reviewer should repeat the entire process, only this time as if each exit were his exit. He should therefore determine what is required for him to take the exit, and negotiate the exit lane. For example, taking a left exit represents an unusual maneuver, particularly to a driver in the right-hand lane. Similarly, even if the exit does not require an unusual maneuver (i.e., a standard right-hand exit), a driver may still be required to perform an unusual maneuver in the course of negotiating the exit. For example, a driver may have to come to a full stop at the end of the exit ramp.

The unusual maneuvers by other vehicles are also obtained from the procedure outlined previously. In this case, when tracing the maneuvers that a driver must perform in any lane, the reviewer is, in essence, specifying the "maneuvers by other vehicles for every other lane on the main line. To complete this determination, the reviewer should "finger drive" every entrance onto the road, following the procedure outlined previously. He should note any unusual maneuver in entering onto the main line, such as an unusual weaving maneuver or entering on the right and exiting shortly thereafter on the left.

## Changes

The reviewer should note, as a special feature, any changes in the road. These include:

1. Changes in Cross Section-Such features as lane additions and lane drops are special features. The lane drop is the more critical change from a safety standpoint. Changes in shoulders and medians should also be noted.
2. Changes in Environment-The reviewer should note any changes in the roadway environment, including changes from rural to urban (determined from the abutting land-use determinations).
3. Changes in Legal Environment-Including changes in speed limit, lane restrictions, etc., occurring on the segment of roadway being reviewed.

## Off-Line Restrictions

The reviewer should note off-line restrictions, both as safety hazards and for potential line-of-sight blockage.

Common off-line restrictions include abutments, piers, underpasses, and steep cuts.

## Sight-Line Restrictions

While reviewing the plans for extremes in geometrics and off-line restrictions, the reviewer should be noting potential sight-line restrictions.

## Environmental Consequences

A determination of ambient climatological and lighting conditions should be made.

Examples of climatological conditions that should be considered are freezing roadways (particularly on overpasses and bridges), heavy snow obscuring pavement markings, and fog in low-lying areas.

Special-feature ambient lighting conditions include sun in the driver's eyes, high background lighting due to gas stations, motels, etc., off the right-of-way of the road, and unlit sections where complex geometric conditions exist.

## Miscellaneous Features

In analyzing the plans, the reviewer should note miscellaneous special features, including:

1. Construction.
2. Fallen rock zones.
3. Animal crossings.
4. Traffic signals.
5. Speed/vehicle restrictions.
6. Toll booths.
7. Railroad crossings.
8. Poor road surfaces.
9. Private signs (billboards).

## Heavy Traffic

Heavy traffic conditions with congestion potential should be noted.

## High-Signal Areas

The most common high-signal locations are found in urban areas and at interchanges. High-signal areas are usually locations where one or more special features occur.

The determination of high-signal areas is, to a large extent, a matter of engineering judgment. However, the reviewer should treat any location or area that he suspects to be a high-signal area as if it were one.

High-signal areas are not necessarily associated with short stretches of roadway. There may be entire sections of road that are high-signal areas. These are usually found on urban freeways. Therefore, if such is the case (i.e., if the stretch of road is through an urban area or is a beltway around a metropolitan area) the reviewer would probably be correct in considering the entire stretch as being a high-signal area.

## Identification of Vigilance Locations

The reviewer should note long stretches of roadway where relatively little is occurring, such as on rural freeways. These are areas that should be considered in terms of potential vigilance problems. In these cases, lack of change, information presentation, and challenge can cause drivers to become bored and inattentive and thereby miss important information.

## SPECIFICATION OF POTENTIAL INFORMATION SYSTEM PROBLEMS

The next step in the procedure consists of specifying potential information system problems. This provides the re-
viewer with a context in which to evaluate the information system. In this step the reviewer notes potential ramifications of the special-feature area to the driver as well as consequences of deficient information display.

## Consequences of Special-Feature Areas and Deficiencies in Information Display

Special-feature areas have the potential of creating driving difficulty and information display problems. Special-feature areas may also have associated problems because of deficient, misleading, or erroneous information presentation. The following summarizes prevalent consequences of special-feature areas and information display deficiencies:

1. Confusion.
2. Directional uncertainty.
3. Environmental uncertainty.
4. Errors.
5. Missed signals.
6. Path uncertainty.
7. Service uncertainty.
8. Vehicle control difficulty.

The reviewer should evaluate each special-feature area and note potential information display problems directly onto the marking and signing plans.

The recommended procedure is for the reviewer to make an initial determination of potential consequences of the special-feature areas. He should then proceed to the next phase of the review procedure-the review of the displayed information. In the course of reviewing the plans, the reviewer determines whether the displayed information resolves the potential problem or adds to it. If the displayed information does not resolve the potentially adverse consequence and/or if it adds to or creates a problem in and of itself, the reviewer then applies the remedial techniques that are discussed in the last phase of the procedure.

## Confusion

Driver confusion is a result of one or more of the following factors, taken singly or in combination:

1. Ambiguity-Usually associated with displayed information. When the reviewer reviews specific information carriers, he should evaluate message content for ambiguity.
2. A Priori Knowledge Deficiency-When displayed information is outside of the repertoire of the driver, confusion can result. Hence, a priori knowledge deficiency may be due to presentation of inadequate information or due to language deficiencies.
3. Expectancy Violations-Any time that the expectancies of the driver are violated, confusion can result. Although expectancy violations can occur from displayed information problems, they are more likely to be associated with special-feature areas. Most unusual interchange design features violate expectancies. Extremes in roadway geometrics are violations of expectancies, as are unusual maneuvers. Changes in cross section and legal environments are violations in drivers expectancies. Environ-
mental consequences also violate expectancies, as do most miscellaneous features.
4. High-Signal Areas-Confusion can occur in highsignal areas. However, the confusion is not necessarily due to the high-signal area per se, but to overload, missed signals, or rapid, and/or complex decision making.
5. High Information Challenge--Usually associated with formal information display, high information content can cause confusion. When the reviewer reviews specific information carriers, he should evaluate message content for high information carriers as well as decision complexity.
6. Missing, Erroneous, or Inadequate InformationThe driver can become confused due to information needed but not displayed, and when erroneously or inadequately displayed. The reviewer should evaluate information needs as a factor of special features to determine if displayed information is missing, erroneous, or inadequate. In addition, the reviewer should recognize that missed signals due to incorrect load-shedding can cause confusion. This is associated with high-signal areas and where high task-loading is involved, as in extremes in geometrics and/or unusual maneuvers.
7. Negative Information-Associated with formal information display, negative information can lead to driver confusion.
8. Overload-When the driver is overloaded he can become confused. Overload will be most prevalent in high-signal areas.
9. Pacing-When the attention demands of the roadway are too fast for the driver to handle them, the driver can be confused. Again, most commonly found in highsignal areas.
10. Uncertainty: Directional, Environmental, Path, Service-Uncertainty associated with these aspects of driving can cause confusion.

As the foregoing indicates, confusion may be associated with all special-feature areas. The reviewer can therefore assign confusion as a likely consequence at every specialfeature area, but must also ascertain why confusion is a potential consequence.

## Directional Uncertainty

Directional uncertainty is a condition where the driver is unsure of the proper navigational course to follow at a choice point (i.e., interchange). This concept is to be differentiated from path uncertainty (see the following) where the driver is uncertain as to his proper guidance path, although the two can occur in conjunction with each other (at unusual interchanges).

Directional uncertainty is to be suspected for all interchanges, both standard and unusual. The reviewer should recognize that there will be some directional uncertainty at each exit and interchange, and that the guide signs associated with the interchange will either resolve the uncertainty or add to it. (The assumption made for the review procedure is that the driver taking an exit is a stranger and that each exit is to be evaluated as if it were the exit that the driver was supposed to take.) If the guide signs do not resolve the directional uncertainty, or
if they add to it, confusion will result. Therefore, the reviewer should note directional uncertainty at each interchange, and evaluate guide sign legend in the context of resolving this uncertainty.

## Environmental Uncertainty

The reviewer should consider the possibility of environmental uncertainty. This term refers to the uncertainty on the part of the driver on how to adjust his driving to adverse environmental conditions. This may be a problem in snow areas, where icing occurs (e.g., bridges, overpasses), and in areas of dense fog. If this condition is suspected, the reviewer should determine if it is critical enough to warrant special treatments.

## Errors

A consequence of special-feature areas may be errors by the driver committed due to missing or erroneous information, or due to any of the factors listed previously under "Confusion."

One of the things that the reviewer may do is consider the potential consequences of errors, recognizing that drivers will, even under optimum conditions, commit errors.

However, because there are situations and locations where errors are more apt to occur, specifically in highsignal areas and at interchanges where path uncertainty and directional uncertainty is prevalent, the reviewer should consider the consequence of errors at these locations.

For example, if the driver were to take a wrong exit, does he have any opportunity to easily return to the main route? (i.e., is the system "forgiving"?). If, due to path uncertainty, he leaves the road (as in the case of a gore), means must be devised to emphasize the proper path.

## Missed Information

A potential consequence of certain special-feature areas is missed information. A driver would miss information because his attention was not focused on the information displayed, being given instead to another source of information. Thus, several factors must be taken into account with respect to the possibility of missed information at special-feature areas:

1. The attention-gaining characteristic of the information.
2. The competing demands on the driver's attention.
3. The priority of information needs.

The attention-gaining characteristic of the displayed information is a function of the physical characteristics of the information carrier (i.e., its target value, legibility, size, location, etc.). These factors, and their adequacy, must be determined.

With respect to the competing demands on the driver's attention, there are two aspects that must be considered: high-signal areas and high task loading. As in all cases, these can occur either singly or in combination.

The reviewer should consider information being missed as a probability in all high-signal areas. High task loading, as may be expected in the case of extremes in geometrics, and where unusual maneuvers are required, can lead to missed information. The driver is attending to the activity with the high loading and is thus unable to shift his attention to other sources. In either case, missed information is to be suspected whenever an overload is suspected.

Therefore, the reviewer should determine what the task loading is for a particular location (high decision and/or control difficulty being the basis of assigning a high task loading to a particular activity). Once this is accomplished, he can then make a judgment of potential missed information when information other than that required to perform the highly loaded task is presented.

This leads to the third aspect of the missed information factor, the priority of information needs. In the course of his analysis, the reviewer will come across locations where information carriers conflict.

If a potential missed information consequence is determined, the reviewer will have to make a determination of information need priority. This is discussed under the remedial techniques section of the procedure.

## Path Uncertainty

Path uncertainty is a consequence of the driver being unsure of the proper path to take to maintain his safe course. That is, path uncertainty represents the case where the driver may leave the road or take an exit that he did not want to take.

As in the case of directional uncertainty, path uncertainty is most commonly found at unusual interchanges. In addition, path uncertainty can occur in areas where unusual maneuvers are required where extremes in alignment occur and where expectancies are violated.

The reviewer should determine whether path uncertainty is a potential problem by tracing the paths that the driver can take on the plans. Suspected path uncertainty may be a good reason for a field trip.

Path uncertainty should be noted at the suspected locations, and existing information display, particularly markings, should be evaluated in that context.

## Service Uncertainty

Service uncertainty is the condition that occurs when the driver is unsure of the available services on or near the road. Among the services needed by the driver are gas, food, lodgings, and emergency services.

Every time the reviewer notes directional uncertainty, he would not be wrong in noting service uncertainty.

The reviewer should determine what services, if any, are available, and provide the driver with this information. The reviewer should strive to resolve the driver's service uncertainty before he enters long stretches of road with no available services.

## Vehicle Control Difficulty

The reviewer should note that certain locations present the driver with vehicle control difficulty, in addition to the decision difficulty that is associated with confusion, uncertainty, and overload.

Vehicle control difficulty is apt to occur at unusual interchanges, at entrance and exit ramps, at extreme geometric locations, where unusual maneuvers are required, and where environmental conditions present the driver with environmental uncertainty.

When vehicle control difficulty is suspected, consideration should be given to aiding the driver by lowering the posted speed limit or by other measures that ease the driving task.

## EVALUATION OF MARKINGS AND DELINEATION

After steady-state and special-feature areas have been identified and potential information system problems have been noted, the next step in the review is to evaluate markings and delineation.

In implementing this phase, the reviewer might find it expedient to dispose quickly of the steady-state locations before the special-feature areas are considered. For this reason, the discussion of the marking and delineation phase of the design review procedure is structured in terms of the steady-state and special-feature dichotomy.

## Marking and Delineation Review, Steady-State Areas

The review for the marking and delineation portion at steady-state areas and locations is a relatively simple and rapid activity. The primary purpose of markings and delineation is to provide control-related information to the driver (see Table H-1). Because the control function is continuous throughout the driving task, information displayed via roadway markings and delineation should always be available to the driver.

Therefore, markings and delineation should be continuous through all steady-state areas and locations. That is, lane markings, edge markings and delineators should always be displayed.

As a matter of course, for marking and delineation as well as for all aspects of the highway information system display, the reviewer should check for applicable signing manual conformance. Any deviations from the manuals must be for a good reason.

## Marking and Delineation Review, Special-Feature Areas

The reviewer should proceed to review the special-feature areas markings and delineation. Here, the best way to proceed is to start at the point furthest downstream, and to review the markings and delineation for each special feature consecutively, ensuring that the transition from a steady-state location to a special-feature location, and/or from one special-feature location to another, is smooth.

Although the discussion relative to the marking and delineation portion of the review for special-feature areas is being presented for each of the special-feature area types in accordance with the scheme presented previously in "Identification of Probable Problem Locations," the
reviewer does not have to go from type to type to apply the review procedure.

At this stage the reviewer will have a description of the special feature under consideration and a specification of potential problems that may be associated with the area.

Using this, the reviewer should evaluate the markings and delineation for the special-feature area or location and determine whether the treatment is suitable or whether it must be supplemented by fixed signing or other means.

## Standard Interchanges

Interchanges are separated into exits or entrances and each is evaluated in turn.

Because the exits and entrances are classified as standard, the only evaluation that the reviewer must make is whether the exit and entrance markings are in accordance with the signing manual. In addition, the ramp should be evaluated after the exit is reviewed to ensure that the markings and delineation are there, and in accordance with the manuals.

## Unusual Interchanges

The markings and delineation at unusual interchanges should be carefully evaluated, as these special features are prime suspects for path confusion.

Whereas markings and delineation are prime information display carriers in steady-state areas, the situation is not the same for special-feature areas, particularly where path confusion and/or violated expectancies are involved. In these situations, the marking and delineation channel might be complementary to, or act as a redundant message for information displayed to the driver by signs. That is, while markings and delineation are the primary information carrier for such information needs as lateral location and road alignment, they are to be considered as a redundant information source, and therefore not the main information carrier for directional information needs and features such as expectancy violations (e.g., lane drops, left exits). In certain instances, such as at unusual gores where path confusion may be present, markings serve as a complementary information display treatment to the exit sign.

Therefore, the reviewer must recognize that when he evaluates markings and delineation for a special-feature location, he must do so in the context of other displayed information. Thus, he must make a determination if the markings and delineation are the prime information source or a redundant or complimentary source of information.

In most interchanges, the markings are complementary to the signing. The reviewer should evaluate them in that context. The reviewer should ensure that all edge, lane, gore, and recovery markings are present, and that continuous delineators are used.

Among the interchange features that may prove the most difficult, and that may require special treatments, are bifurcations, multiple exits/entrances, exits on curves, left exits, and lane drops at exits.

In evaluating the need for special treatment, the reviewer might find it useful to make an in-field evaluation of the interchange. The reviewer is expected to use his
engineering judgment in applying marking and delineation treatments. However, he must ensure that the markings are always available to the driver, and that path confusion does not occur.

After reviewing the markings for the exits and entrances, the reviewer should evaluate the markings and delineations for exit lanes, again applying the rule of continuity of markings and continuous delineations. If lane assignment type of signing is used, the reviewer must make sure that the markings complement and do not conflict with the sign message.

## Extremes in Roadway Geometrics

In the case of extremes in horizontal alignment, the reviewer, in addition to ensuring continuity of markings and continuous delineation, should recognize that markings and delineation will not be sufficient. The reviewer must therefore, in his evaluation of extreme horizontal alignment treatments, ensure that the proper warning sign is used. If the alignment is extreme, and in a high traffic area with multiple lanes of traffic, the reviewer should consider restrictions on lane changing. This treatment is used when the driver may be so overloaded by the high task loading of tracking an extreme horizontal alignment change that he would be unable to also attend to traffic movements.

## Unusual Maneuvers

Unusual maneuvers may require more than marking and delineation to satisfy information needs.

However, markings and delineation should be applied as a redundant information source and/or a means of lane use control. The important factor to keep in mind when evaluating information display for unusual maneuvers is that the driver must be provided with advance warning and, in some instances, directed to the proper lane. This implies signing rather than markings, although pavement markings such as arrows may prove a useful additional information source. Again, a degree of engineering judgment is required.

## Changes

The use of standard markings and delineation to provide information relative to cross-section changes, especially lane drops, must be supplemented by fixed signing and possibly special pavement markings. However, when traffic density is high, and when environmental conditions such as snow on the roadway occur, even treatments such as arrows on the pavement, although useful, are not sufficient, and signing must be used.

## Off-Line Restrictions

The use of markings and delineation to warn the driver of off-line restrictions (e.g., abutments, narrow bridges) is recommended. The reviewer should determine whether delineation, zebra striping, and other marking are used for potentially hazardous off-line obstacles. In implementing this activity, the reviewer should be aware that sign posts,
especially in gores, are off-line restrictions that should be delineated.

## Miscellaneous Features

The use of markings for features such as construction, lane-use restrictions, tool areas, and railroad crossings is well documented in the manuals.

The reviewer should evaluate these features for manual conformance.

## EVALUATION OF REGULATORY AND WARNING SIGNS

In this phase of the review procedure, the reviewer evaluates warning and regulatory signs. The evaluation of the sign portion of the highway information system is divided into two phases: (1) evaluation of regulatory and warning signs, and (2) evaluation of service and guide signs.

Markings and delineation, which primarily satisfy control information needs, are evaluated in the preceding phase of the procedure; regulatory and warning signs, which primarily satisfy guidance-related information needs, are evaluated in this step; and service and guide signs, which primarily satisfy navigation-related information needs, are evaluated in the next phase.

There is considerable overlap between the three driving elements, just as there is considerable overlap between the three classes of information carriers. However, it is conceptually convenient to structure the driving task into the control-guidance-navigation scheme and to evaluate the highway information system information carriers in this context.

The reviewer should recognize that overlap does exist, and that one information carrier or combinations of information carriers can solve more than one function and can thus satisfy several information needs. For example, the exit speed sign, while serving to tell the driver what speed to take an exit ramp at, also serves to alert the driver (by inference) to the severities of the ramp alignment. An example of how several information carriers combine is the case cited in the previous section, where a combination of markings and a pavement-width transition sign at a lane drop provides a redundant, complementary information display that serves to warn the driver of an unexpected event, and to tell him what to do.

Before the review of regulatory and warning signs is discussed, a word should be said regarding the previously discussed markings and delineation phase of the procedure. Although the markings and delineation phase of the review. procedure is separated from the regulatory and warning sign phase, the reviewer does not necessarily have to separate the two phases. The reason that this procedure separates the two is to accommodate reviewers with separate marking and signing plans.

The point is emphasized that, except for steady-state areas, and special-feature areas where the markings and delineation information carriers serve to provide only location and horizontal alignment information, markings and delineation serve as complementary or redundant information sources. In the latter instance, the merit of the mark-
ings and delineations must be evaluated in the context of the warning and regulatory signing required.

Therefore, the reviewer might find it more convenient to evaluate special-feature signing and markings together. If he chooses to evaluate the two separately, he must reevaluate the marking and delineation treatments after his evaluation of the warning and regulatory signing.

Several points, which follow, are implicit in the procedure and must be kept in mind.

## Manual Conformance

The procedure has been structured with the assumption that the personnel who design the signs and sign placements know how to apply the marking and signing manuals. The reviewer is expected to check each specific information carrier for manual conformance. If the reviewer finds that the signs are not in manual conformance, he must correct them to bring them into conformance, unless there is a compelling reason for non-standard signing and/or sign locations.

## Importance of Regulatory and Warning Signing

There are levels of importance of regulatory and warning signs. That is, there are certain signs that must be displayed to alert the driver to a hazardous situation, others that should be displayed, and others that do not necessarily have to be displayed, but that, for legal or administrative reasons, are required.

For example, signs warning the driver of a lane drop must be displayed, speed limit signs should be displayed, and no littering signs do not necessarily have to be displayed, from a safety standpoint. This is not meant to imply that the last class of signs does not have to be displayed, but rather that these are the signs that can be deleted with the least impact to the driver's safety. In addition, these are the class of signs that can be moved or removed in case of conflicts with other, more important signs.

Although it is not possible tó rank warning and regulatory signing in terms of importance, the reviewer should be able to quickly establish an importance ranking of competing information carriers for a specific special-feature area or location.

## Steady-State Location Involvement

With the exception of certain regulatory signing (e.g., speed limit, emergency parking only), there is almost no need for regulatory or warning signing in steady-state areas, because, by definition, the steady-state area is devoid of situations or events requiring special guidance-related information. However, the steady-state area is, in some instances, the best place to provide the driver with special-feature-related information, because the driver is less likely to be overloaded.

In addition, when a special-feature area is immediately downstream from a steady-state area, information relative to the special-feature area is likely to be positioned in the steady-state area.

Thus, the reviewer, when evaluating special-featurerelated regulatory and warning signing, may deem the
optimum location of these information carriers to be in steady-state areas. It is recommended that, if at all possible, regulatory and warning signing for special features should be either positioned in, or perceivable from, steadystate areas.

The recommended procedure for evaluating warning and regulatory signing is for the reviewer to start at the point furthest downstream and to work his way back upstream to the start of the highway section being reviewed. In the course of this, he should note whether the display information for a special-feature area falls in a steady-state area or in another special-feature area.

All other things being equal, if the information relative to a special-feature area is in a steady-state location, most of the potential problems that may be associated with the information display will have been resolved. If, however, the display of information relative to one special-feature area falls in another special-feature area, the reviewer must recognize that the display of information relative to the first special-feature area may create new problems (particularly with respect to potential overload or missed signals) in the second special-feature area.

## Approach

The philosophy of this procedure is to analyze the highway section by breaking it down into steady-state and specialfeature areas and locations, identifying information needs and potential problems associated with each specific area or location, and evaluating the merit of the proposed or presently existing information system in the context of the identified information needs and potential problems.

The evaluation is accomplished by looking at the highway as if no information were present, and evaluating each class of information carrier by building up the total information system. That is, in the previous phase, the markings and delineation were added and their ability to satisfy information needs and solve potential problems was gauged. In this stage, regulatory and warning signing is added to the markings and delineation and their ability to satisfy information needs and solve potential problems that the markings and delineation could not resolve is determined. The process is iterative, and as more information is added more information needs should be satisfied and more potential problems should be solved. However, the addition of information may also create problems that were not there. Thus, the reviewer is required to determine not only whether the addition of a sign resolves a problem or satisfies an information need, but also whether the addition of the information carrier may lead to new and different problems.

In effect, the reviewer must go back and forth when any additional sign or marking is added. He must first determine whether the added sign fulfills its intended purpose. Then he must determine what effect it has on other elements of the information system. This process must be repeated until the entire information system is evaluated, and only then is the information system evaluated fully.

This process is not necessary for markings and delineation. It is first required during the warning and regulatory signing phase of the procedure. Here, each sign must be
evaluated with respect to each other sign and with respect to markings and delineation.

## Implementation

Starting at the furthest point downstream, the reviewer should evaluate each proposed warning and regulatory sign on the plans. It is recommended that the signing on the plans be reviewed rather than working out new signing.

The reviewer notes the type of location reviewed (for purposes of discussion, a special-feature area is assumed). He evaluates the area and determines which information needs are satisfiable by warning and regulatory signing by referring to Tables $\mathrm{H}-1$ and $\mathrm{H}-2$. The reviewer then notes whether all applicable information needs are satisfied with the proposed signing, evaluating one sign at a time. In cases where the reviewer noted that warning and regulatory signing was required to complement markings, or as the prime information carrier, with redundant markings, he should determine if this has been accomplished.

If the information needs have been satisfied, and the problems solved, the reviewer can proceed to the next area. If the information needs have not been satisfied and/or if the potential problems have not been solved, the reviewer must determine the reasons for this. If the problem is due to a lack of needed warning or regulatory signing, he should add the missing sign(s).

In evaluating warning and regulatory signing, particular attention should be given to location. The sign should not be too close to the change so that the driver does not have enough time to read the sign, make the necessary decisions, and take the appropriate action. The sign also should not be too far removed from the event so that, due to limitations of the driver's short-term memory and/or due to intervening signs or events, the driver may forget or miss the information. For example, if a sign is located to warn a driver of an extreme alignment change, the location should be such as to provide the driver with the requisite warning and provide him with sufficient time to respond.

## Nearness Determination

The procedure to make the nearness determination is as follows. The reviewer must consider the following factors:

1. The posted or prevalent speed on the road.
2. The reading time of the message.
3. The legibility distance.
4. The decision complexity.
5. The control difficulty of the maneuver.

Reading Time.-The reading time of a sign is determined from

$$
R T=2 N / 3
$$

in which $R T=$ reading time in seconds; and $N=$ number of short familiar words or symbols. When applying this formula, the reviewer is to consider each symbol on a warning sign to be equivalent to a short, familiar word.

Legibility Distance.-The legibility distance is determined by applying the " 50 feet to the inch" rule.* By

[^62]knowing what the height of the letters or a symbol on a sign are, the reviewer can determine what the distance is for the sign to be legible (readable). For example, a $10-\mathrm{in}$. letter or symbol is legible at 500 ft .

Decision Complexity.-The decision complexity can be determined readily for regulatory and warning signs because there are no regulatory or warning signs in the manual that have a high decision complexity. Signs either tell the driver what to do (e.g., stop, keep right, turn), or provide him with information that calls for a simple decision (e.g., yield-where the driver has to decide to yield if a vehicle has the right-of-way; speed limit-where the driver has to determine from his speedometer if he is exceeding the speed limit). Those signs that tell the driver what to do take about 0.2 sec ; information requiring a simple decision takes about 0.4 sec . If the reviewer has any doubts as to the decision complexity, he should use the latter figure.

Control Difficulty.--The control difficulty of the maneuver must be calculated. The reviewer should recognize that all control maneuvers take time. The more difficult the control task the more time is required. The reviewer must take this into consideration and assign a task difficulty to each maneuver. "Easy" control maneuvers take from 0.2 to 0.4 sec . Difficult maneuvers could take about 1 sec .

Given the foregoing data, the reviewer evaluates sign location as follows:

1. The legibility distance is determined.
2. The reading time is determined.
3. The decision complexity time is determined.
4. The reading time and decision complexity time are added.
5. The legibility distance is converted into legibility time in seconds by dividing the legibility distance by the design speed in feet/sec.
6. The reading time and decision complexity time are subtracted from the legibility time. If the result is negative, then the sign must be moved upstream or the sign size increased to provide the driver with more time to perceive the sign and make the needed decision. If the result is zero or only slightly positive, the reviewer should ascertain if the sign can be moved further upstream, especially if the control maneuver is difficult. In doing this, the reviewer should compare the remaining time with the control maneuver time and determine if there is sufficient time remaining to implement the control maneuver required. If the remainder is positive (at least 2 to 3 sec remainder) then the reviewer can be assured that the sign is not too close to the event.

## Farness Determination

The second part of the determination requires some engineering judgment on the part of the reviewer. It involves a determination of the remoteness of the sign from the event. The farther away the sign warning of the event is from the event, the more time the driver will have to read and act on the warning or regulatory sign. There is a point, however, when the sign is too far away from the event to be effective. This occurs when the limits of
the short-term memory of the driver are reached (about 2 to 4 sec ) and/or when events such as traffic or other signs intervene.

Therefore, the sign warning of the special feature should be no more than 2 to 4 sec of driving time * away from the event, particularly if other events or different signs intervene. If, however, the special feature is perceivable unaided (taking into account nighttime or extreme visibility conditions), this criterion becomes less critical.

If signs other than those related to the warning for the special-feature area intervene, every effort should be made to remove them. In addition, if there is any possibility that missing of the warning sign could lead to hazardous consequences, repetition of the warning, as well as redundancy of information, should be considered.

To this point, the discussion has dealt directly with only one sign (or group of signs) -needed sign(s) for a special-feature area. However, there are few cases where a needed regulatory or warning sign is the only sign in the area. (Intervening guide and service signs are discussed in the next phase of the procedure.) Dispersed throughout the highway information system will be signs that are required for legislative and administrative reasons, but that may not specifically be needed by a driver to perform his task, and/or that serve as information to a small portion of the traffic stream. Speed-limit signs, no parking signs, etc., fall into the former category; truck restriction signs fall into the latter category.

This is not to imply that these signs do not serve a needed function and that they should be deleted (as a rule, there should be as few signs as possible). In fact, there are instances (notably in low-signal locations where vigilance may be a problem) when these signs are extremely useful.

The next step, after the first warning or regulatory sign has been reviewed, is to evaluate the next sign upstream, which, for purposes of discussion, will be assumed to be a non-safety-related, non-special-feature-associated, regulatory sign.

The most important thing to consider in reviewing this class of signs is to make sure that they do not interfere with safety-related needed warning or regulatory signing. If a relatively unimportant (from a safety standpoint) sign does not block a needed sign or interfere with the action required by a needed sign, the reviewer can initially approve of its use, except in the case of high-signal areas, or where it is located in an adjacent special-feature area farther upstream. In these cases, the reviewer must reserve his approval until all aspects of the information system have been evaluated.

So far, the discussion has dealt with the cases where the display of a needed regulatory or warning sign falls in an adjacent steady-state area. However, if the location of information for a special-feature area is located in an adjacent or overlapping special-feature area upstream, the reviewer must realize that there may be problems with the subsequent location. If this situation occurs, the reviewer may have to reevaluate the location of the original sign when reviewing the subsequent location.

[^63]The next case to be considered is when the next sign upstream from the first sign evaluated is one associated with a needed, and safety related, aspect of subsequent special features. If this sign does not present any blockage or intervening information display problems, it should be evaluated following the procedure set forth previously under the discussion for the first sign. If, however, this information presentation blocks or in any other way interferes with the first sign, the reviewer must determine how to resolve the conflict. There should be few instances when conflicts of this nature occur, but the reviewer should be on his guard to catch this type of problem.

The most obvious way to resolve conflicts of this nature is to move one or both signs so that neither blockage nor interference occurs. In doing this, some of the effectiveness of one or both of the signs may be lost. However, as in the case of the most tradeoffs, the reviewer must be prepared to accept less than optimum locations.

A final, although not necessarily desirable, solution is to change some aspect of the situation to alleviate the problem. This could range from reducing speed to lane-use control to changing the geometrics of the road.

In reviewing subsequent special-feature locations, the reviewer must repeat the foregoing process, both for every warning and regulatory sign on the plans, and for every warning and regulatory sign added by the reviewer.

Thus, the reviewer must cover each sign, remembering to check warning and regulatory signing on exit ramps as well, until all warning and regulatory signs have been reviewed.

In the course of reviewing each sign, the reviewer should check for such things as ambiguity. However, these factors should not be a problem if the applicable signing manual is followed.

At the end of this phase the reviewer should be satisfied that all information needs that can be satisfied by warning and regulatory signing are satisfied, that the signs are in accordance with the manuals insofar as possible, that the required signs are in the most optimum locations, that there is no blockage, and that intervening warning and regulatory signing does not interfere with other needed safety-related warning and regulatory signing.

What is not fully assessed at this point is whether there is too much signing, especially in high-signal areas, and whether the warning and regulatory signing in some way interferes with the guide and service signing.

With regard to the first point, the reviewer's engineering judgment should provide him with a preliminary indication as to whether too much signing is present. As to the second point, the review of the guide and service signing, discussed subsequently, will provide him with answers.

## EVALUATION OF SERVICE AND GUIDE SIGNS

Following the evaluation of regulatory and warning signing, the reviewer should evaluate the service and guide signs on the signing plans. Here, the reviewer follows essentially the same review procedure for the regulatory and warning signs. That is, the reviewer evaluates service and guide signs with respect to each other and with respect to the previously evaluated signing and markings.

There are, however, important differences in this phase. For one, the messages for markings and delineation and for warning and regulatory signing are relatively fixed by the manuals, whereas there is considerable latitude regarding guide and service messages. A second difference is that the guide signs will not, in most instances, be able to satisfy information needs for all drivers. That is, there is no way that guide signs can provide the driver with all potential destinations, nor is there any way for the reviewer to know the trip plans of all drivers.

A third difference is that there is a distinct possibility that drivers may become confused by the message on a guide sign. These messages also contain a much higher potential for ambiguity.

There is no need for the reviewer to evaluate service signing separate and apart from guide signing. The scheme of discussing service signing separate from guide signing is only for purposes of facilitating the discussion of each. It is recommended that the reviewer do not separate the two reviews, but rather that he implement the guide and service signing reviews together.

## Service Signing

Service signing is applicable primarily to rural areas. Advance signs for services should, if at all possible, be presented to the driver in steady-state areas.
In evaluating service signing, the reviewer should attempt to determine whether the gas, FOOD, lodgings signs are in fact true-perhaps by a field review of the area.
The reviewer should recognize that the driver needs service signing, especially in rural areas, when there is long interchange spacing, when needed services are only infrequently available, and when these services are not directly visible from the highway.

In evaluating service signing the reviewer should adhere to the method described previously-that of ensuring that display information does not block or in any other way interfere with other needed signing. Service signing represents a class of signs that, usually, can readily be moved in case of conflict with more important information carriers or can be removed completely from high-signal locations.

It is expected that the reviewer will review the service signing in conjunction with guide signing so that he can evaluate if service signing interferes in any way with guide signing. In the case of conflicts, the guide signing should take precedence. However, this does not mean that service signing can or should be deleted. As pointed out elsewhere, service uncertainty is a possibility. If the driver is not provided with needed service information, there is a possibility that he may take the first available exit, thus becoming lost and without the needed service. What is suggested is that service information, although important, is not as important as most safety-related or directional signing. It is, however, more important than certain regulatory signing, as previously discussed, and certain miscellaneous guide signs. Therefore, when service signing is being evaluated with respect to, for example, a DO NOT cross median sign or an historical marker sign, the service sign would take precedence.

## Guide Signing

The primary emphasis in this phase of the review procedure is on an evaluation of guide signing. To accomplish this activity, the reviewer must have, in addition to the signing plans used in the previous phases of the procedure, copies of readily available service station maps of the area. Origin and destination information, if available, will also prove useful, although it is not essential.

Using the maps and the signing plans, the reviewer reviews guide signs on the basis of their ability to resolve the directional uncertainty of the greatest number of drivers. In addition to this primary review function, the reviewer checks for manual conformance and consistency, ambiguity, and the impact of the guide signs relative to other system elements.

In a discussion of guide signing factors, the most attention is given to advance guide and exit direction signs. However, consideration is given to the entire gamut of guide signing available to the designer to satisfy the directional information needs of the user.

## Approach to Evaluating Advance Guide and Exit Direction Signs-Message Content

The approach used to evaluate messages is to ensure that the sign's message content resolves the directional uncertainty of the greatest number of users.

Certain assumptions have been made on the basis of the best estimates of population attributes. These assumptions are:

1. Signing is for the stranger-The assumption is made that the guide signing is for a stranger using the road. This implies that the primary purpose of guide sign messages is to provide directional information to users unfamiliar with the road and the area. However, consideration will be given to the occasional driver of the road and the commuter or everyday user of the road. The assumption is that if the needs of the stranger are satisfied, the needs of the occasional user (i.e., "local stranger") and the everyday user will also be satisfied.
2. Signing takes into account the user's trip plan-A second assumption is that the user has a trip plan; that is, he has a potential destination, and knows how to get there, if not exactly, at least in general terms. This assumes that the user knows which roads to take to reach his destination, and what his destination is.
3. Trip plan formulated from a map-Finally, it is assumed that the user has formulated his trip plan using available maps. For this reason, the reviewer should have available maps of the area.

## Implementation of Advance Guide and Exit Direction Signing Evaluation-Message Content

No guide signing presently in the manual can fully satisfy the directional information needs of all of the highway users at all times. This is due to the shortcomings of present mapping practices, the variability of possible user trip plans, and the lack of control that the sign designer and reviewer has over trip plans and maps. These reasons,
plus the lack of data as to which maps are used by whom, and how trip plans are formulated, make it apparent that there is no way that a sign reviewer can be given a formula for determining the proper message to put on a guide sign.

What is attainable, however, is the optimization of guide sign messages so that the greatest number of highway users will be served by the sign. The reviewer can evaluate the sign messages in the context of human factors principles and thus minimize uncertainity while maximizing usability by all drivers. This will be a guiding principle in evaluating sign messages in this phase of the review.

In essence, then, the review procedure for guide signing, insofar as messages are concerned, is to evaluate the message content of signs for the following:

1. Applicability of message content.
2. Absence of ambiguity.
3. Absence of unlabeled alternatives.
4. Avoidance of negative reasoning.
5. Continuity and consistency.
6. Rejectability.
7. Relatability.

Applicability of Message Content.-The reviewer's main task in evaluating guide signing is to ensure that the message content of guide signs is correct and applies to the greatest number of drivers using the highway. It is assumed that the guide sign will be directed primarily toward the stranger with a map and a simple trip plan, while accommodating the rest of the highway-user population.

The recommended procedure for the reviewer to follow (including ensuring that the signs are in accordance with the applicable manuals) is to start at the point furthest downstream (i.e., the interchange) and proceed upstream, evaluating the exit direction sign first and then, after the reviewer is satisfied as to the correctness of that sign, evaluating the advance guide sign(s).

This procedure cannot tell the reviewer what the sign message should be. However, what is being presented is a way to aid the reviewer in applying his engineering judgment by providing him with a series of factors and questions.

Because the approach to the evaluation is based on signing for the stranger with a map and a trip plan, the reviewer should attempt to put himself in the place of the driver for whom the signing is directed. That is, the reviewer should attempt to reproduce the driver's possible trip plans, which include the interchange under consideration, and try to determine what the driver would expect, and need to know. In doing this, the reviewer should use the available maps that he has gathered for the evaluation to obtain an indication of potential alternative routes, roads, and destinations and how they are described (if at all) on the maps.

A second important input that the reviewer should obtain in structuring his engineering judgment is the answer to the question, "What is the purpose for the interchange?" That is, who does the interchange serve? The reviewer should try to determine what users and what needs are served by the particular interchange under
consideration. In performing this activity, the reviewer will be greatly aided by available origin and destination data as well as information regarding major traffic generators, both present and proposed. Among the determinations that the reviewer may make are:

1. The interchange is a freeway-to-freeway transfer point.
2. The interchange serves an area such as a rural location, a resort area, or a park.
3. The interchange serves to connect the road to a major arterial.
4. The interchange leads to a major generator such as an airport, a stadium, or a university.
5. The interchange connects to a city street or rural route.

After making these determinations, the reviewer should consider "How is the interchange best described?" In most cases, this can be accomplished by using an exit numbering system. If this or a similar system is employed, the reviewer has, only to ensure consecutiveness and uniqueness (i.e., if there are two exits such as a "north" and "south," he has to ensure that the sign reflects this, and that the advance also reflects this).

When no such numbering system is in use, the reviewer's task becomes more difficult. Here, he must evaluate what the exit serves, and how it can best be noted. If it serves a major arterial, the exit is perhaps best identified as the Route 110 exit. If it services an area, the exit is perhaps best identified as the efland exit; etc. Even if exits are numbered, the foregoing process should be carried out as the identification by other than number represents a good and recommended example of redundancy.

Finally, the reviewer should consider the following as questions that the driver needs to have answered:

1. Where am I?
2. Where does the interchange lead to?

After the reviewer has accomplished these activities in the context of the "stranger with a map," he should consider other classes of drivers-notably the so-called "local stranger" (i.e., the driver who is familiar with the general area serviced by the roadway but unfamiliar with the specific location serviced by the interchange). In this case, the reviewer, who should be somewhat familiar with the area, should try to determine whether roads and locations might be known by names other than those that appear on maps. For example, I-495 in New York State is known as the "Long Island Expressway" (which does not appear on many maps); $\mathrm{I}-90$ in Chicago is known as the "Eisenhower Expressway"; I-94 in Detroit is the "Lodge Freeway"; and most Los Angeles Freeways are known by names (e.g., the "San Diego Freeway" is I-405, the "Santa Monica Freeway" is I-10). If he finds this to be the case, he should attempt to ensure that the local name is included on the sign, if possible, thus providing applicability to the "local stranger" while providing an additional redundant source of information.

By this time the reviewer should recognize that, due to all the foregoing factors, plus those that are discussed
subsequently, nearly all guide signs (especially those associated with complex interchanges where many alternatives are possible) may require considerable tradeoffs insofar as message content is concerned. The reviewer should apply engineering judgment in evaluating guide sign message content to ensure that the foregoing and subsequent factors are considered in selecting the message used.

Absence of Ambiguity.-Once a message is deemed to be applicable, the reviewer should check for ambiguity. Ambiguity occurs where the information is unclear, obscure, has more than one meaning, or creates uncertainty. Hopefully, the process whereby applicability has been determined will eliminate obscurity. Similarly, if redundancy is employed correctly, there should be no duality in meaning. Thus, the uniqueness of an interchange, where a particular interchange cannot be confused with any other interchange on the road, is an important principle to bear in mind when evaluating guide messages for ambiguity.

Absence of Unlabeled Alternatives.-The absence of unlabeled alternatives is especially important at unusual interchanges, such as tangent off-ramps and bifurcations where path confusion as to the main line of the highway may occur.

An example is the case where the exit is labeled, but the main line, which is not self-evident, is not. In cases of unusual interchanges, the reviewer should ensure that there are no unlabeled alternatives.

Avoidance of Negative Reasoning.-Negative reasoning is the situation where a driver reads a guide sign with a particular destination and, because his destination is not included, reasons that the exit could not possibly lead to his destination.

Because the reviewer cannot possibly control the trip plans that a driver has formulated, there is relatively little that he can do to avoid negative reasoning. However, the reviewer should recognize the existence of this potential form of error on the part of the driver. He should avoid the use of destinations unless they are obvious, and, in the case of equiprobable destinations served by a particular interchange, include both or neither on the sign.

Continuity and Consistency.-As the reviewer proceeds in the review, particularly from advance guide to exit direction signing, he must check for continuity. He should never allow an exit direction sign to surprise the driver. The legend on the advance guide sign and the exit direction sign must be consistent. That is, if the advance guide sign says utopia 1 mile, the exit direction sign must say uTOPIA.

Similarly, there should be consistency between all guide signs on the road. If the road being signed is a continuation of an existing road, the signing for the "old" to the "new" road must also be consistent.

Rejectability.-Up to now, the discussion assumed that the exit under consideration was the desired exit. However, the reviewer must be aware that, for most of the traffic stream, most exits are not in the driver's trip plan. Therefore, one of the things that a guide sign should tell the driver is that the exit is not his exit. In high-signal areas, particularly, the sign should be easily and quickly rejected by the drivers not needing the exit.

Relatability.-For the driver using the exit, the obverse of rejectability is relatability. That is, the sign should enable the driver taking the exit to relate the legend to his trip plan. In addition, relatability also enables drivers not taking an exit to relate the information contained on the guide signing to his trip plan.

Summary.-There are many factors that the reviewer must be aware of when evaluating guide signing. Each has its own particular merits insofar as that portion of the problem is concerned. For example, the more redundancy is employed, the less the chance of ambiguity. Similarly, the more information placed on the sign, the more drivers will be served. However, the more information there is on the sign, the less the relatability and rejectability, and the more the chance for ambiguity due to repeated messages.

The reviewer is faced with the need to limit the message content, thus necessitating reliance on engineering judgment to effect the required tradeoffs.

The way in which the tradeoff goes is determined by the situation at each interchange, whether it is in a high- or a low-signal area, the type of exit configuration, the number of users using the interchange, the consequence of errors at the interchange, and the legal and administrative constraints that the designer and reviewer must live with. All factors should be weighed carefully before a final decision is made for each sign used.

## Evaluation of Total Directional Information Display

The evaluation of message content for exit direction and advance guide signing, although the major part of the review, is not the only task that the reviewer has. He still has to evaluate other directional carriers such as Route Shields, Cardinal Direction Markers, and D\&D displays, as well as the guide signs evaluated previously in this report with respect to each other and with respect to other signing and markings.

The location of each sign must be evaluated on the basis of legibility distance, reading time, prevailing speed on the road, and decision complexity. Here, the decision complexity will be greater than for most regulatory or warning times, especially if unusual maneuvers or complex directional decisions are to be made.

Consideration must also be given to blockage and intervening messages. As in the case of the evaluation of the warning and regulatory signing, the reviewer must ensure that no blockage occurs and that there is little likelihood of intervening messages between needed signals. If there is blockage, the reviewer should strive to reposition the sign doing the blocking. In the case of blockage due to such things as abutments or other natural features, every attempt should be made to move the sign to where it can be visible.

When one sign blocks the other, the reviewer must strive to move the sign or signs to a position where there is no blockage. As far as directional signing goes, the advance guide and exit direction signs are the most important, with other directional signs assuming correspondingly lesser importance. Thus, when a route marker, for
example, blocks a safety-related regulatory or warning sign, the latter takes precedence. This is the concept of primacy, which is discussed in the next section.

With regard to intervening or interfering information display, the procedure discussed previously in "Evaluation of Regulatory and Warning Signs" is to be applied. Move the less-important intervening sign, if possible; delete it if it cannot be moved but can be deleted; or apply repetition if neither can be accomplished.

In this manner, all directional signing is to be evaluated. In the course of the evaluation, the reviewer is to ensure that the information needs are satisfied to the greatest extent practicable. If an information need is not satisfied, the reviewer should add the information carrier needed to satisfy the need, and then evaluate the impact of the added sign to the present information system using the procedure set forth previously.

After all signs have been evaluated, there may still be conflicts and problems that the reviewer is unable to resolve. These should be noted and consideration given to the techniques discussed in the following.

## FINAL CHECK AND APPLICATION OF CORRECTIVE TECHNIQUES

The final step in the review procedure is to reevaluate the information system to determine if there are any deficiencies with any aspect of the information display and/or if conflicts that have been noted in the course of the review can be resolved through the application of corrective techniques.

## Deficiencies

The reviewer should check the total information display to determine if any of the following deficiencies are present:

1. Non-display of needed information.
2. Inadequate or incomplete display of needed information.
3. Erroneous display of needed information.
4. Ambiguous display of needed information.
5. Information not in the best form for the driver to use it.
6. Information not displayed in the optimum location for use.
7. Conflict among carriers.
8. Too much information display to the driver.
9. Too little information displayed.
10. Transmission of information inhibited by physical, climatological, or ambient lighting factors.

Proper application of the design review procedure should ensure that most of these deficiencies will not be present. However, it is useful to reevaluate the total information system in the context of these common deficiencies as a final check on the plans. Three areas should receive special attention. These are: (1) Conflict among carriers, (2) Too much information displayed to the driver, and (3) Too little information displayed to the driver.

In the course of the review, the reviewer will have noted the cases of conflicting information and the cases where there may be too much information (i.e., high-signal areas). With respect to too little information displayed to the driver, the deficiencies may not be as obvious. Therefore, as part of the final check, the reviewer should pay close attention to long steady-state stretches, such as rural locations, where relatively little is happening. Here, the problem is lack of vigilance. The reviewer should recognize that prolonged stretches where nothing much is occurring can reduce the driver's alertness and ability to respond to information.

Thus, if the reviewer notes long steady-state areas with relatively few special-feature areas, and if these specialfeature areas violate expectancies, require unusual maneuvers, are associated with extremes in geometrics, or in any other way pose a safety hazard, and the reviewer finds that relatively little information is displayed in the steadystate areas, he can deem these areas as being locations where too little information is being displayed.

The following discusses primarily the three deficiencies noted.

## Application of Corrective Techniques

The reviewer can attempt to apply several corrective techniques to the remaining problem areas. This section indicates what they are and how they may be used. The teechniquues are: (1) primacy, (2) spreading, and (3) redesign.

## Primacy

The concept of primacy is implied throughout the entire development of this procedure. Primacy provides the reviewer with a basis for evaluating competing information carriers and for removing information carriers in highsignal areas. Primacy takes into account the levels of driving (i.e., control, guidance, and navigation) and structures information needs associated with each in terms of their importance to the driving task.

As a general rule, needs associated with vehicle control are more prime (hence, more important) than needs associated with guidance which, in turn, are more prime than needs associated with navigation. Most of the controlrelated information needs amenable to satisfaction by the highway information system are adequately satisfied by markings that are continuously displayed and generally do not conflict with guidance or navigational information. Conflicts, therefore, are generally between information carriers associated with guidance-related information and/ or with navigational-related information.

In the case of these conflicts, the reviewer usually can resolve the conflict by determining the consequence of non-satisfaction of either of the two information needs, with safety taking precedence over reduction of directional uncertainty. Hence, regulatory and warning signing of a critical nature, such as that associated with violations of expectancies, high task loaded vehicle control maneuvers at extreme geometrical areas, or where unusual maneuvers
occur, should be displayed rather than guide signing in case of conflict. Similarly, while the driver is executing these difficult vehicle control maneuvers, he should not be given less prime directional information, or less prime regulatory information.

In high-signal areas the primacy rule should also be considered. If too much information is displayed, the driver may not receive needed information related to safety. Here again, after all extraneous regulatory and warning information is removed, the less prime directional information may have to be removed, or at least reduced. That is, exits must be identified, but less message content may be the solution.

## Spreading

In the discussion on conflicting and competing information needs, the point is made that extraneous and less prime information might have to be moved or deleted. This is not to say that these carriers should not be displayed somewhere. However, the "somewhere" should be the steady-state areas. This is the concept of spreadingspreading information throughout the highway so as to equalize the information challenge as much as possible. The virtue of spreading is that it helps in low vigilance areas while taking away signing in high demand areas.

Spreading may even be accomplished in high-signal areas by moving carriers around enough to keep a steady level of information display, rather than having build-ups at interchanges. Thus, one of the tradeoffs that the reviewer may deem necessary is to spread information and sacrifice some optimum locations.

## Redesign

Redesign of the highway may be the only reasonable solution for certain problem locations. These are the locations that, owing to circumstances, are not amenable to information display. Recommending redesign is the most extreme measure that a reviewer can take, and must be used only as a last resort. Slight modifications to the roadway, such as extending an acceleration lane, removing an obstruction, or highway lighting may be all that is required. There are other cases where extensive roadway geometric redesign is the only solution. Here, the reviewer must be sure that there is no other way to solve the problem. However, the reviewer must recognize that his first responsibility is to the user, and that an information system that does not satisfy his needs could lead to confusion, errors, and accidents.

## CHAPTER TWO: HUMAN FACTORS PRINCIPLES USEFUL TO THE TRAFFIC ENGINEER

The following presents concepts and principles relative to user characteristics and display techniques that should be considered by designers, reviewers, and engineers. These principles may also be used as a glossary of human factors terminology applicable to highway information systems.

The following principles are included:

1. A priori knowledge.
2. Advance warning.
3. Ambient conditions.
4. Ambiguity.
5. Arousal.
6. Attention.
7. Coding.
8. Confusion.
9. Consistency.
10. Continuity.
11. Cross-modal redundancy.
12. Decisions.
13. Design driver.
14. Expectancy.
15. Extraneous information.
16. Forgiving system.
17. General warning.
18. High-signal areas.
19. Information challenge.
20. Information needs of the driver.
21. Levels of performance.
22. Load-shedding.
23. Median-case driver.
24. Negative information.
25. Overload.
26. Path confusion.
27. Primacy.
28. Redundancy.
29. Repetition.
30. Short-term memory.
31. Specific warnings.
32. Spreading.
33. Task loading.
34. Unusual maneuvers.
35. User-centered.
36. Vigilance.
37. Visual factors.
38. Worst-case design.

## A PRIORI KNOWLEDGE

Definition: The sum total of knowledge and information that the driver brings into the driving task. Included under a priori knowledge are the driver's driving experience, his knowledge of rules and regulations, his knowledge of the language, his knowledge of the various symbols and codes employed, and his trip plan.

Principles: When reviewing an information system, recognize the body of a priori knowledge possessed by the user. Assume that he knows how to drive, but consider situations outside his experience such as unusual maneuvers and special features. Assume that the driver is familiar with certain rules and regulations such as driving on the right side and keeping in lane. Do not expect drivers from out-of-state to know rules and regulations unique to the state that the road is in. Provide the driver with important information regarding these special rules and regulations, and inform him if a change in rules occurs (as in the case of changing jurisdictions). Assume that
the driver knows the English language, but recognize that his level of literacy may not be beyond the grade-school level. Keep verbal messages simple to accommodate the semi-literate driver. Assume that the local driver is familiar with the various symbols and codes contained in the driver's manual for the state. Do not assume that he knows any more than that regarding symbols and codes. Recognize that the driver has a trip plan but do not expect him to know the area. Sign for the stranger with a map. Obtain maps from the area and try to reproduce the driver's formulation of a trip plan using the maps available. Do not indicate destinations not on the map.

## ADVANCE WARNING

Definition: A means of displaying information to the driver about the occurrences of important or relevant events, features, and situations prior to their occurrence.

Principles: Advance warnings should be used in cases where the occurrence of important or relevant events, features, and/or situations is not perceivable unaided and

1. unUSUAL maneuvers are required (e.g., compound curve).
2. Difficult vehicle control actions are required (e.g., extremes in alignment).
3. expectations are violated (e.g., left exit), or unexpected events occur (e.g., traffic signals, railroad crossings).
4. Changes from the steady state occur (change in cross section, change in speed limit).

In addition, advanced warnings should be used to inform the driver of upcoming exits and interchanges. Advanced warnings are useful in spreading situations, where high information challenge precludes the display of certain important but less prime (see Primacy) information. When reviewing advance warnings, the reviewer should recognize the limitations of the SHORT-TERM MEMORY and be aware of the temporal and spatial relationships involved so as to give the driver adequate time to make and implement a decision (see decisions).

## AMBIENT CONDITIONS

Definition: Those important environmental factors that affect the reception and use of information and/or generate information needs in and of themselves. In the context of the information system design review, the most important ambient conditions are ambient climatological factors and ambient lighting conditions, although ambient noise conditions may also be relevant.

Principles: Take into account prevailing ambient conditions when reviewing information system designs. Determine whether extremes in ambient climatological conditions exist. Consider the attenuating characteristics of certain climatological conditions such as snow and fog. Recognize that ambient climatological conditions can affect other system elements and generate needs themselves (e.g., bridge freezes before roadway, slippery when wet). Determine whether the highway is to be lighted, and design signs and markings and delineations accordingly. If possible, determine what the lighting off-the-road may be and
whether this will function as distractions or unwanted signals. Evaluate the direction of the road and determine whether sun will be in the driver's eyes, making certain signing positions impractical (e.g., overhead signs).

## AMBIGUITY

Definition: Information that is unclear, obscure, that creates uncertainty, or that can have more than one meaning.

Principles: Ambiguity must be avoided. An ambiguous or unclear message is one that does not tell the driver what to do, as for example DANGER ahead. An obscure message is not relevant to the driver, as for example sCenic route. Information that creates uncertainty is found in areas of path confusion. An example of a message that can have more than one meaning is RESUME SAFE SPEED.

## AROUSAL

Definition: A means to alert the driver to the presence of important information.

Principles: Reserve arousal mechanisms (e.g., bells, rumble strips) for use in hazardous situations, as for example at rail grade crossings. Use in conjunction with cross-modal redundancy, with the specific information displayed via the visual channel.

## ATTENTION

Definition: The active selection of a signal out of the environment, and the process of emphasizing that signal. Also, the adjustment of the sensory receptor for optimal reception of the stimulus.

Principles: When visual information is being presented, it should be recognized that the driver must attend to the signal in order to use it. Thus, it is important that the information has a high attention-gaining value. The driver is able to attend to only one signal at a time, and he handles information from many sources by sampling the environment and LOAD-SHEDDING to attend to a different source. The designer and reviewer should, therefore, identify special-feature and high-signal areas and consider the fact that the driver's attention span is limited and may be exceeded. It should be realized that too much information may be displayed, and that the driver may miss important signals due to improper load-shedding or inability to attend to all sources. Extraneous informaTION should be removed, and less prime (see Primacy) information spread (see spreading). Complex information (see decisions) should also be simplified if possible.

## CODING

Definition: The process whereby a body of information is converted into a set of symbols that serves to substitute for the original body of information. Coding is usually employed when the original information is too large or complex to handle, but can also serve as a mechanism of REDUNDANCY.

Principles: Although the processes of coding a complex or a large body of information are a powerful tool for enabling the driver to handle the information, especially under the time pressures involved in driving, the designer and reviewer should be cautious in employing this technique. For a code to be usable, it must be within the body of a Priori knowledge of the driver. The designer and reviewer should use only the codes contained in the manuals that can be reasonably expected to be known by the driver (i.e., the color alphabet and shape codes). The driver should not be expected to know some of the more technical codes such as the delineator codes or the Interstate and U.S. Primary Route number codes. If a code other than that just described is deemed necessary, it should be applied evolutionarily and should be self-learning if possible.

## CONFUSION

Definition: A state of bewilderment, lack of clear thinking, and disorientation on the part of the driver.

Principles: All information displayed to the driver should be reviewed to determine if it can be a potential source of confusion to the driver. An ambiguous message is a potential source of confusion (see also path confusIon). In addition, the reviewer should recognize that high information challenge, high task loading, highsignal areas, violations of expectancy, and unusual maneuvers can also lead to driver confusion.

## CONSISTENCY

Definition: Agreement and harmony of all parts of the information system to each other and to the information system as a whole.

Principles: The information system designer and reviewer should ensure that the same treatments are applied throughout the entire stretch of highway. For example, if an Interstate route becomes a state route (e.g., I-495 in New York becomes NY 495), the same information display techniques should be used on both portions as long as there is no change in design standards.

## CONTINUITY

Definition: Each sign in a sequence designed in context with those that preceded it.

Principles: Continuity should be achieved, especially for relatively long sections of highway, so that the driver can verify his progress and thus reduce any uncertainty.

## CROSS-MODAL REDUNDANCY

Definition: The process whereby the same information is displayed to the driver on several sensory reception channels, as for example visual and auditory.

Principles: Cross-modal redundancy can be used for arousal of the driver to a hazardous situation (e.g., bells at a railroad crossing), to emphasize important information (e.g., raised lane markers), and in areas where vigilance may be a problem (e.g., rumble strips). Because
the auditory channel may be occupied by the driver listening to a radio or engaging in conversation, and because audio signals may be attenuated by closed windows, the audio channel should be used only for unspecified (or general) warnings. Specific information should be displayed visually.

## DECISIONS

Definition: The formulation of a course of action on the part of the driver, based on information received in transit.

Principles: Recognize that every aspect of driving involves the driver receiving information, making decisions on the basis of this information, and executing vehicle control actions (even if it involves not taking any action). Thus, implicit in any display of information is that, if received and attended to, it leads to the driver making a decision. Because every decision involves some time, the designer and reviewer should be aware that making a decision means that the driver has less time to attend to another source of information and to formulate another decision. Three important aspects of decisions and deci-sion-making should be considered: (1) number of decisions, (2) complexity of decisions, and (3) decision rate. Each aspect should be evaluated in the context of the situation and the demands placed on the driver. Situations where the factors may be especially important are where the information challenge is high, where there is high task loading, in high-signal areas, in special feature, where EXPECTANCIES are violated and where UNUSUAL maneuvers are required. If it is deemed that there may be problems, the area under consideration should be evaluated in terms of the number of decisions that must be made. The reviewer can accomplish this by counting the sources of information generated by the information system (e.g., signs, markings) and the sources of information generated by the other system elements (e.g., traffic). If it appears that the quantity of information is excessive (the design review in Chapter One provides a means for making such a determination), the number of decisions should be minimized (see spreading). In conjunction with the foregoing, the designer and reviewer should evaluate the decision complexity and strive to make complex decisions simple. Finally, the designer and reviewer should evaluate the decision rate (i.e., the quantity of decisions per unit time). The reviewer should always minimize the rate at which decisions must be made, making each decision as simple as possible.

## DESIGN DRIVER

Definition: The driver for whom the information system is designed. Important design driver attributes include age, sex, a priori knowledge, and visual reception attributes (see median-case driver and worst-case design).

Principles: Design and evaluate highway information systems, taking into account the attributes of the design driver. Because the implementation of highway information systems is evolutionary rather than revolutionary, recognize that present practices are directed toward a median, rather than a worst-CASE DESIGN. Evaluate likely
user populations to determine if a median design is adequate. For example, certain areas (such as those close to Mexico and French Canada) may include populations with a large mix of non-English-speaking drivers. Areas close to retirement locations may include populations with a large number of elderly people. In these cases, it may be useful to evaluate information systems in terms of modified design driver attributes rather than median design driver attributes.

## EXPECTANCY

Definition: The anticipation on the part of the driver of the occurrence or non-occurrence of events and situations formulated as a function of his experience and a Priori knowledge. Also, the disposition to respond to events and situations as a function of experience and a Priori KNOWLEDGE, or as a function of information displayed in transit.

Principles: Information system designers and reviewers should evaluate aspects of the highway to determine whether expectancies are violated, and recognize that any violation of driver expectancies can lead to CONFUSION, uncertainty, and improper Load-shedding. For example, lane drops and left exits violate normal driver expectancies. These and other events that are counter to normal expectancies should be signed for, with adequate advance warning provided. Thus, it should be recognized that signs serve to structure EXPECTANCY so that the principles of CONTINUITY should be maintained.

## EXTRANEOUS INFORMATION

Definition: Information that is not applicable to the driver or that is not needed by the driver.

Principles: Extraneous information display should be avoided, especially in high-signal areas. In these cases, the designer and reviewer should evaluate displayed information to ascertain which information carriers are extraneous (e.g., signs such as historical marker ahead). These extraneous signs should be spread, if possible, or deleted, if not.

## FORGIVING SYSTEM

Definition: A system that takes into account that the driver may miss a signal or make an error and gives him another opportunity.

Principles: Recognize that the driver may miss a sign due to improper LoAD-shedding or truck blockage, etc., and if possible give him a second chance (see repetition). If possible, inform him of the consequences of his having missed his signal (e.g., next exit 10 miles, next service area 41 miles).

## GENERAL WARNING

Definition: Information warning the driver about an upcoming condition but not informing the driver what to do. Useful for arousal but should not be used in lieu of specific warnings.

Principles: Use general warning for arousal. Use SPECIFIC WARNINGS where required.

## HIGH-SIGNAL AREAS

Definition: Locations on the highway where, due to the nature and interaction of the highway system elements (roadway geometrics, interchange spacing, traffic density, required maneuvers, etc.), and due to the formal display of information (signs, markings), there is a clustering of information sources. Typical of high-signal areas are urban arterials and complex interchanges.

Principles: The designer and reviewer should identify high-signal areas and recognize that they are potential sources of overload and confusion. The designer and reviewer should identify each information source and determine, on the basis of being extraneous and primacy, which signals can be SPREAD and which can be eliminated.

## INFORMATION CHALLENGE

Definition: The quantity of information contained in any information carrier.

Principles: The designer and reviewer can estimate the information challenge of any given carrier and translate it into an estimate of decision times. An information carrier that requires no decisions but only provides information (e.g., pavement lane and edge markers) represents the simplest case in information challenge and decision complexity. However, even these carriers take a finite amount of decision time, about 0.2 sec (a "simple" reaction time). The next higher or more complex case in terms of information challenge is the information carrier that can lead to a single decision, either A or B. For example, an exit direction sign leads to a decision either to take the exit or to remain on the main line of the highway. This is still a simple case in information challenge and decision complexity, although the time required to make the decision increases to about 0.4 sec (about two "simple" reaction times). As the information challenge increases the decision complexity increases and the time to make the decision increases. The relationship expressing the time needed to resolve the information challenge is $(N+1) \times$ (simple reaction time $)$. In the foregoing expression $N$ equals the number of equally possible alternative decisions. The designer and reviewer should evaluate the information challenge of an information carrier and estimate the decision time involved. The information challenge should be minimized, especially in HIGHsignal areas and where the driver's attention is limited. It should also be recognized that, when the information challenge becomes high, the driver may not be able to handle the information and make proper decisions. High information challenge could lead to errors, missed signals, or CONFUSION.

## INFORMATION NEEDS OF THE DRIVER

Definition: The body of information required by the driver to perform the driving task safely, comfortably, conveniently, and efficiently.

Principles: Driving is a complex activity that consists of many tasks. To perform these tasks, the driver must rely on information that he receives in transit as well as knowledge that he possesses (see a priori knowledge). It is the function of an infurmation system to provide the driver with the information he needs when he needs it, and in the form that he can best use it. The designer and reviewer should be aware of the tasks involved in driving and the information needs associated with them, and should apply and evaluate the information system designed to satisfy these needs on the basis of whether, and how well, the needs are satisfied. The designer and reviewer should know what the needs are for any given location and the techniques that are available to satisfy these needs. When there are conflicts as to which of several information needs to satisfy, the designer and the reviewer should apply the criterion of safety to resolve the conflict, followed by efficiency, convenience, and comfort.

## LEVELS OF PERFORMANCE

Definition: A way of conceptualizing the driving task in terms of its constituent subtasks. The levels of performance concept groups the various subtasks into a hierarchical organization corresponding to the level of physical and mental complexity required of the driver to perform the subtasks. The lower end of hierarchy, the microperformance level, takes into account aspects of the driving task relating to vehicle control, putting the car in motion and keeping it on the road. It is continuous throughout the driving task, and does not present the experienced driver with physical or mental complexity. The intermediate level of the hierarchy, the situational performance level, is involved with guidance (i.e., negotiating the vehicle safely through the highway system relative to the elements of the system, particularly geometric features, obstacles, and traffic). The situational level may present the driver with physical and mental complexity. At the highest level, the macroperformance, aspects of the driving task involved in navigation (i.e., direction finding and route following as well as trip planning) are involved. The macroperformance is therefore entirely mental, and may pose the greatest complexity to the driver, especially the unfamiliar driver. (See Primacy.)

Principles: The information system should always satisfy the microperformance information needs of The driver, because these needs are continuous. The information system should satisfy the situational information needs of THE DRIVER when they occur, with sufficient time to respond to these needs and thus maintain safety. The information system should satisfy the macroperformance information needs when they can be used by the driver most comfortably and conveniently, while not interfering with the more prime (see Primacy) and more safety-related microperformance and situational performance levels of performance.

## LOAD-SHEDDING

Definition: The process whereby a driver shifts his attenTION from one source of information to another.

Principles: Recognize that in high-signal areas the driver will be sampling sources of information by loadshedding. Facilitate his load-shedding behavior by providing him with simple information Challenge, advance WARNING, REPETITION, REDUNDANCY, and by reducing the number of information carriers.

## MEDIAN-CASE DRIVER

Definition: A representation of the attributes possessed by the 50 th percentile driver (i.e., 50 percent of the driving population is "better" and 50 percent of the drivers are "worse" with respect to the important attributes enumerated). The median-case driver is the "average" driver. The important attributes for an information system are:

1. Vision: $20 / 20$ visual acuity.
2. Age: 38 years.
3. Education: 10.5 years of formal education.
4. A Priori Knowledge (see a priori knowledge):

Knows how to drive; knows rules and regulations; is fluent in English; is literate; has knowledge of symbols in manual; has a trip plan formulated from available maps.

## (See also design driver and worst-Case design.)

Principles: When reviewing and evaluating highway information systems, recognize that the DESIGN DRIVER will possess the foregoing attributes. Take these attributes into account, but bear in mind that the attributes possessed by median-case drivers are not possessed by worst-case drivers, and that important segments of the driving population may be excluded or placed at a disadvantage through the implementation of a median-case highway information system.

## NEGATIVE INFORMATION

Definition: Information telling the driver what not to do.
Principles: Because negative information tells a driver what he cannot do without telling him what to do, it may lead to confusion or uncertainty. Therefore, the use of negative information should be avoided, and, if it must be used, it should be supplemented by telling the driver what to do.

## OVERLOAD

Definition: A condition where the driver is unable to perceive and/or use the information displayed.

Principles: The driver should never be overloaded because overload can lead to CONFUSION, improper loadshedding (see attention), missed signals, or uncertainty. The information system should be reviewed and evaluated to identify potential overload situations.

## PATH CONFUSION

Definition: A condition where, owing to AMBiguity or unusual roadway geometrics, the driver is confused as to his proper path.

Principles: Evaluate roadway for potential areas of path confusion, particularly at interchanges or in areas where unusual maneuvers are required. Determine if information display techniques contribute to path confusion or
whether treatments are inadequate for the situation. If so, determine whether special treatments or advance warnings can help. Path confusion should be avoided, especially in the design stages.

## PRIMACY

Definition: A concept based on level of performance that enables a determination to be made as to which INFORMATION NEEDS should be satisfied when information carriers conflict. Essentially, microperformance (vehicle control) information should be continuous, situational performance information (guidance) should be displayed when needed, and macroperformance information (navigation) should be displayed when needed but subordinate to situational performance if it conflicts, and safety is compromised.

Principles: When evaluating an information system, in the case of conflicts apply the principles of primacy to resolve the conflicts (see also spreading, task loading, levels of performance).

## REDUNDANCY

Definition: The property of a message that reduces the probability of error and ambiguity while enhancing detectability. Redundancy is usually accomplished by presenting the same message in two or more different ways. Redundancy may be employed on the same carrier as in the Interstate service signs that employ a blue background as well as a verbal message. Redundancy may also be employed on different carriers-for example, pavement markings and a verbal message. See also cross-modal REDUNDANCY.

Principles: Redundancy should be fully used in the design and application of a highway information system. When reviewing a highway information system, the reviewer should investigate the possibility of employing redundancy when ambiguity is suspected. The designer and reviewer should recognize that the use of redundancy can also facilitate a driver's load-shedding process. This is accomplished by virtue of the enhancement of detectability brought about if coding such as shape and color codes are employed as a mechanism of redundancy. These coded messages employ less information challenge and take less time thạ verbal messages.

## REPETITION

Definition: A technique whereby important information is displayed in several successive locations for emphasis and to ensure that it is not missed.

Principles: Employ repetition to emphasize important messages, where limitations of the SHORT-TERM MEMORY may lead to missed signals, as a means of redundancy, and in conjunction with spreading. When using repetition, the designer and reviewer should evaluate the total situation and ensure that by employing repetition not too much information is displayed.

## SHORT-TERM MEMORY (ALSO IMMEDIATE MEMORY)

Definition: The span of memory of the driver for what has been presented within the past few seconds. The driver operates as a two-step device with respect to memory. Received information, as for example from an advance guide sign, is first stored in the short-term memory for immediate use. If the message is relevant, it is then transferred to long-term storage. If the message is not relevant or does not have immediate use, or is not reinforced (as for example, if no repetition is employed) the message may be forgotten. Thus, the short-term memory is limited in terms of time between the receipt of information and the action required by its use to a few seconds. In addition, the capacity of the short-term memory is limited so that only a few messages can be stored. That is, the presentation of several different messages in a sequence may cause the first message to be forgotten. Finally, an attempt to recall information in the short-term memory may cause subsequent information to be missed.

Principles: It should be recognized that the short-term memory of drivers is limited, both in terms of duration between receipt of information and action required by the information, and also in terms of quantity of information that can be remembered by the driver. The designer and reviewer should consider the time lag between presentation of information and its action. Employ repetition to ensure that the information is not forgotten. Thus, shortterm memory mechanisms are most critical to adVance warning mechanisms. Consideration should be given to subsequent information display and a determination should be made as to whether there may be inhibition on, or due to additional different intervening information presentation.

## SPECIFIC WARNINGS

Definition: Information warning the driver about an upcoming condition and telling him what to do (see advance warning). Specific warnings minimize uncertanity. (See also general warning.)

Principles: advance warning should be specific rather than general.

## SPREADING

Definition: The process whereby extraneous or lower primacy information (when conflicts exist) is removed from high-signal areas or special feature areas and repositioned to steady-state areas. See also vigilance.

Principles: Spreading is applicable as a solution when too much information is displayed (see high-Signal areas), when there are conflicts among displayed information, when extraneous information must be displayed due to legal and administrative requirements, when the driver is overloaded, when applying repetition, and when lack of vigilance may be a problem.

## TASK LOADING

Definition: The demands that an action or subtask place on the driver. Low task loading signifies a relatively easy task for the driver, such as straight-line steering or simple speed control. High task loading signifies a relatively difficult task for the driver, such as a difficult weaving maneuver (see unusual maneuvers) or a complex alignment change or driving on ice.

Principles: When evaluating information presentation, determine what the driver's task loading is. Recognize that a high task loading will take the driver's attention. Do not present information other than that required to do the task under high task loading; for example, do not present guide information on sharp curves or on entrance or exit ramps. Investigate spreading in accordance with primacy as a solution.

## UNUSUAL MANEUVERS

Definition: A location or area where the driver is required to execute complex or unexpected vehicle control actions.

Principles: The driver should be provided with advance warning information whenever he is required to execute an unusual maneuver, or when the traffic stream may execute unusual maneuvers. Recognize that unusual maneuvers can create uncertainty or CONFUSION.

## USER-CENTERED

Definition: An information system design taking into account the characteristics and attributes of the user.
Principles: All aspects of the highway information system should be user-centered. If tradeoffs are required, as for example between administrative factors and userrelated aspects of a particular information carrier, the tradeoffs should be in favor of the human factors.

## VIGILANCE

Definition: Alertness to information and events that may occur.

Principles: Recognize that long stretches where relatively little is occurring, as for example in the case of rural freeways, can present a problem in vigilance. That is, the driver may miss important signals. Among the methods that may be employed to overcome this problem are arousal and spreading.

## VISUAL FACTORS

Definition: Important factors of vision that should be considered in the display of information. These factors include:

1. Acuity: Sharpness or keenness of vision.
2. Adaption: The process whereby the eye becomes sensitized, either to darkness or light.
3. Color Vision: The ability of the driver to discriminate between colors.
4. Field of Vision: The portion of the environment that the driver sees without moving his head or eyes.

Principles: Because the highway information system is primarily a visual one, attention should be paid to visual factors in the design of information. The visual acuity of the driver must be considered in selecting sign letter heights. The designer and reviewer should take into account the differences between day- and night-adapted eyes. Consideration should be given to the color-blind driver, as for example uniform positioning of red, yellow, and green traffic signals.

## WORST-CASE DESIGN

Definition: A design that accommodates the fifth percentile driver (i.e., 95 percent of the driving population is "better" with respect to the important attributes enumerated). Worst-case driver attributes are:

1. Vision: 20/70 visual acuity.
2. Age: Over 70.
3. Education: Less than 4 years.
4. A Priori Knowledge (see a priori knowledge): Is a novice; not fluent in English; may be illiterate; does not know symbols from manuals; has no trip plan.
(See also median-Case driver, design driver.)
Principles: Although a worst-case highway information system design would be the most desirable in that it would accommodate the greatest number of highway users, such a design probably is not feasible. However, the designer and reviewer should evaluate the potential users of the particular highway in question to determine whether mediancase designs are adequate. Consideration should be given to modifying certain information carrier designs to accommodate special cases.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Rep.<br>No. Title

-* A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research-Intermediate Report (Proj. 4-3(2)), $\quad 81 \mathrm{p}$,- $\$ 1 * 80$
1 Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., \$2.80
2 An Introduction to Guidelines for Satellite Studies of Pavement Performance (Prof 1-1), 19 p., ., $\$ 1.80$
2A Guidelines for Satellite Studies of $e$ Pavement Performance, 85 p. +9 figs., 26 tables, 4 app., $\quad \$ 3.00$
3 Improved Criteria for-Traffic Signals at Individual Intersections-Interim Report (Pioj. 3-5), 36 p., \$1.60
4 Non-Chemical ${ }^{\text {² }}$ Methods of:Snow and Ice Control ${ }^{\text {n }}$ onHighway Structures (Proj. 6-2), $\quad 74 \mathrm{p}$., $\quad \$ 3.20$
5 Effects of Different Methods of Stockpiling Aggre-gates-Interim Report (Proj. 10-3), 48p., $\$ 2.00$
6 Means of Locating and Communicating with Disabled Vehicles-Interim Report (Proj. 3-4), 56 p. $\$ 320$
7 Comparison of Different Methods of Mesuring Pavement Condition-Interim Report (Proj. $)^{2}$ ), 29 p., $\quad \$ 1.80$.
8 Synthetic Aggregates for Highway Construction (Proj. 4-4), $\quad 13$ p., $\quad \$ 1.00$
9 Traffic Surveillance ${ }^{\text {and }}$.Means of ${ }_{3}$ 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, $\mathrm{p}, \mathrm{M}, 80$
12 Identification of Aggregates Causing Poor Concrete Performance When Frozen-Interim Report (Proj. 4-3(1)), $\quad 47 \mathrm{p}$., $\quad \$ 3.00$
13 Running Cost of Motor Vehicles as Affected by Highi- way Design-Interim Report (Proj. 2-5), 43 p., \$2.80
14 Density and Moisture Content Measurements by Nuclear Methods-I Interim Report (Proj. 10-5), 32 p., $\quad \$ 3.00$
15 Identification of Concrete Aggregates Exhibiting Frost Susceptibilify-Interim Report (Proj. 4-3(2)), 66 p., $\quad \$ 4.00$
16 Protective Coaftings to Prevent Deterioration of Con-
 $\$ 1.60$
17 Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $\$ 6.00$
18 Comhunity Consequences of Highway-Improvement (P)

19 Economical and Effective Deicing Agents for Use on Highway Structurres (Proj. 6-1), 19 p., $\$ 1.20$

## No. Title

20 Economic Study of Roadway Lighting (Proj. 50-4), 77 p., $\quad \$ 3.20$
21 Detecting Variations in Inad-Carrying Capacity of Flexible Pavements (Proj. 1-5), $\quad 30$ p. $\$ 1.40$
22 Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), $\quad 69 \mathrm{p} ., \quad \$ 2.60$
23 Methods for Reducing' Corrosion of Reinforcing Steel $\cdot($ Proj. $6=4), \quad 22$ p., $\quad \$ 1.40$
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 Unifórm Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), $33 \mathrm{p} ., \mathrm{m}+\mathrm{m}$ \$ 1.60
27 Physical Factors Influencing Resistance of Concrete to Deicing Agents ( P roj. 6-5), 41 p ., $\$ 2.00$
28 Surveillance Methods and Ways and Means of Communication with Drivers (Proj. 3-2), 66 p., $\quad \$ 2.60$
29 Digital Computer-Controlled Traffic Signal System for asmall City (Proj. 3-2), 82 p., $\quad \$ 4.00$
30 Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), $\quad 33$ p., $\quad \$ 1.60$
31 A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $\quad \$ 2.00$
32 Improved Criteria for Traffic Signals at Individual Intersections (Proj. ${ }^{4}-5$ ), ,. 134 p., $\quad \$ 5.00$
33 Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $\$ 3!60$
34 Evaluation of "Cönstruction Control ProceduresInterim Report (Proj. 10-2), 117 p., $\quad \$ 5.00$
35 Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $\quad \$ 5.00$
36 Highway Guardrails-A Review of Current Practice (Proj. 15-1), $\quad 33$ p., $\quad \$ 1.60$
37 Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), $\quad 80$ p., $\quad \$ 3.60$ Evaluation of-Ravement Joint and Crack Sealing Materials and Practices' (Proj. 9-3), $\quad 40$ p., $\quad \$ 2.00$ Factors Involved in the Design of Asphaltic Pavement'Sürfaces' (Pröj. 1-8), $\quad 112$ p., $\quad \$ 5.00$
40 Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), $40 \mathrm{p} ., \quad \$ 2.00$
41 Effect of Control Devices on Traffic Operations (Prof 3-6), $83 \mathrm{p} ., \quad \$ 3.60$
-42 $=$ Interstate. Highway Maintenance Requirements and Unit Maintenance ${ }_{5}$ Expenditure Index (Proj. 14-1), 144 p., $\$ 5.60^{\cdots}$.
43 Density and Moisture Content Measurements by

44 Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $\quad \$ 1.40$
45 Development of Improved Pavement Marking Ma-terials-Laboratory Phase (Proj. 5-5), 24 p., \$1.40
$46^{-m}$ Effects ${ }^{\ldots}$ of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $\$ 4.60$
47 Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), $\quad 173$ p., $\quad \$ 6.40$
48 Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $\quad \$ 3.20$
49 National Survey of Transportation Attitudes and $\therefore=$ Behavior-Phase I Summary Report (Proj. 20-4), 71 p., $-\$ 3.20$

Rep.
No. Title
50 Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $\quad \$ 5.20$
51 Sensing and Communication Between Vehicles (Proj. 3-3), $\quad 105$ p., $\quad \$ 5.00$
52 Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $\$ 3.80$
53 Multiple Use of Lands Within Highway Rights-ofWay (Proj. 7-6), 68 p., $\quad \$ 3.20$
54 Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $\quad \$ 2.60$
55 Research Needs in Highway Transportation (Proj. 20-2), $\quad 66$ p., $\quad \$ 2.80$
56 Scenic Easements-Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $\$ 6.40$
57 Factors Influencing Modal Trip Assignment (Proj. 8 -2), $\quad 78$ p., $\quad \$ 3.20$
58 Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $\$ 3.60$
59 Standard Measurements for Satellite Road Test Program (Proj. 1-6), $\quad 78$ p., $\quad \$ 3.20$
60 Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2) 148 p., $\quad \$ 6.00$
61 Evaluation of Studded Tires-Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $\$ 3.00$
62 Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols (Proj. 7-1), 144 p., $\$ 5.60$
63 Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $\quad \$ 4.00$
64 Motorists' Needs and Services on Interstate Highways (Proj. 7-7), $\quad 88$ p., $\quad \$ 3.60$
65 One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $\quad \$ 1.40$
66 Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $\quad \$ 2.80$
67 Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), $\quad 45$ p., $\quad \$ 2.20$
68 Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 310), $\quad 38 \mathrm{p}$., $\quad \$ 2.00$

69 Evaluation of Construction Control ProceduresAggregate Gradation Variations and Effects (Proj. 10-2A), $\quad 58$ p., $\quad \$ 2.80$
70 Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $\quad \$ 3.00$
71 Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $\quad \$ 2.80$
72 Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., \$2.20
73 Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5/1), 55 p., $\quad \$ 2.80$
74 Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $\quad \$ 2.80$
74A Protective Coatings for Highway Structural SteelLiterature Survey (Proj. 4-6), 275 p., $\quad \$ 8.00$
74B Protective Coatings for Highway Structural SteelCurrent Highway Practices (Proj. 4-6), 102 p., $\$ 4.00$
75 Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $\$ 3.60$

Rep.
No. Title
76 Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., $\quad \$ 2.00$
77 Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $\quad \$ 3.80$
78 Highway Noise-Measurement, Simulation, and Mixed Reactions (Proj. 3-7), 78 p., $\$ 3.20$
79 Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $\quad \$ 6.40$
80 Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), $\quad 120$ p., $\quad \$ 5.20$
81 Moving Behavior and Residential Choice-A National Survey (Proj. 8-6), 129 p., $\quad \$ 5.60$
82 National Survey of Transportation Attitudes and Behavior-Phase II Analysis Report (Proj. 20-4), 89 p., $\quad \$ 4.00$
83 Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $\quad \$ 2.80$
84 Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), $\quad 48$ p., $\quad \$ 2.40$
85 Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $\quad \$ 1.80$
86 Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $\quad \$ 3.20$
87 Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $\$ 2.00$
88 Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $\$ 2.00$
89 Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $\quad \$ 3.20$
90 Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $\quad \$ 4.00$
91 Effects of Deicing Salts on Water Quality and Biota -Literature Review and Recommended Research (Proj. 16-1), 70 p., $\quad \$ 3.20$
92 Valuation and Conaemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $\$ 2.60$
93 Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., \$6.20
94 Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $\quad \$ 1.80$
95 Highway Fog (Proj. 5-6), 48 p., $\$ 2.40$
96 Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $\$ 5.40$
97 Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., \$2.60
98 Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), $\quad 98$ p. $\quad \$ 5.00$
99 Visual Requirements in Night Driving (Proj. 5-3), 38 p., $\quad \$ 2.60$
100 Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $\$ 3.40$
101 Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $\quad \$ 3.60$
102 Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), $\quad 114$ p., $\quad \$ 5.40$
103 Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $\quad \$ 5.00$
104 Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., $\quad \$ 4.40$

Rep.
No. Title
105 Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $\quad \$ 5.00$
106 Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $\$ 3.40$
107 New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $\quad \$ 2.40$
108 Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), $\quad 75$ p., $\quad \$ 4.00$
109 Elastomeric Bearing Research (Proj. 12-9), 53 p., $\$ 3.00$
110 Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $\quad \$ 4.40$
111 Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $\quad \$ 5.20$
112 Junkyard Valuation-Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $\quad \$ 2.60$
113 Optimizing Flow on Existing Street Networks (Proj. 3-14), $\quad 414$ p., $\quad \$ 15.60$
114 Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $\quad \$ 2.60$
115 Guardrail Performance and Design (Proj. 15-1 (2)), 70 p., $\quad \$ 3.60$
116 Structural Analysis and Design of Pipe Culverts (Proj. $15-3$ ), $\quad 155 \mathrm{p} ., \quad \$ 6.40$
117 Highway Noise-A Design Guide for Highway Engineers (Proj. 3-7), $\quad 79$ p., $\quad \$ 4.60$
118 Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), $\quad 96$ p., $\quad \$ 5.20$
119 Control of Highway Advertising Signs-Some Legal Problems (Proj. 11-3(1)), 72 p., $\quad \$ 3.60$
120 Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), $\quad 90$ p., $\quad \$ 4.80$
121 Protection of Highway Utility (Proj. 8-5), 115 p., $\$ 5.60$
122 Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., \$13.60
123 Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12) $\quad 239 \mathrm{p} ., \quad \$ 9.60$

## Synthesis of Highway Practice

## No. Title

1 Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., $\quad \$ 2.20$
2 Bridge $\Lambda$ pproach Design and Construction Practices (Proj. 20-5, Topic 2), $\quad 30$ p., $\quad \$ 2.00$
3 Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), $\quad 38$ p., $\quad \$ 2.20$
4 Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), $\quad 28 \mathrm{p} ., \quad \$ 2.20$

5 Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., $\quad \$ 2.40$
6 Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., $\quad \$ 2.40$
7 Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., $\quad \$ 2.40$
8 Construction of Embankments (Proj. 20-5, Topic 9), 38 p., $\quad \$ 2.40$

THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by President Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as an official-yet independent-adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE HIGHWAY RESEARCH BOARD, organized November 11, 1920, as an agency of the Division of Engineering, is a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Federal Highway Administration, and many other organizations interested in the development of transportation. The purpose of the Board is to advance knowledge concerning the nature and performance of transportation systems, through the stimulation of research and dissemination of information derived therefrom.

HIGHWAY RESEARCH BOARD
national academy of sciences-national research council 2101 Constitution Avenue Washington, D. C. 20418

## address correction requested




[^0]:    * It is assumed that persons with an 1Q of 70 or less would not have the requisite psychomotor skills to pass a driving test.

[^1]:    * These values, and almost all other technical and statistical data in this section, are derived from various issues of the Engineering Specifications and Statistical Issue of Automotive Industries $(18,114)$.

[^2]:    * 54 percent of 1969 model U.S.-made passenger automobiles had

[^3]:    * This ignores vehicle operation in parking lots, garages, driveways, and other locations not on the public highway system. The term "highway" is defined as ". . . the entire area included within the right-of-way of a public way for purposes of vehicular travel" (20).

[^4]:    * Except for some of the electronic and other techniques, discussed in Appendix $F$, that aid at the receiving as well as at the transmitting end.

[^5]:    * Private communication from Dr. Harmer E. Davis, ITTE, UCLA. ** NCHRP Project 20-8, "Interactive Graphic Systems for Highway Design," is designed to address itself to this problem.

[^6]:    * Average passenger vehicle occupancy is 1.5 (5).
    ** In this technical sense "noise" refers to "any disturbance or interference, apart from the wanted signals. . . ." (39)

[^7]:    * ARI refers to the Advisory, Restrictive, or Inhibitory factors that cannot be specifically categorized under vehicle, road, traffic, service, or directional.

[^8]:    a Certain information needs can be assigned to more than one category. When such is the case, the need will only be included in its highest primacy
    ocation.
    ${ }^{\text {b }}$ The term "climatological" refers to road surface conditions resulting from climatological factors or road surface conditions that are the same as those resulting from climatological conditions.
    c The optimum condition is the "null" case of the "type need."
    ${ }^{d}$ Advanced warning of condition.
    e Applicable to driver in median lane only (microperformance case).
    ${ }^{f}$ Applicable to driver in shoulder lane only (microperformance case).

[^9]:    a Applicable to "service-macro" destinations.

[^10]:    * Unidimensional stimuli are stimuli having only a single physical quantity, as in frequency, loudness, etc., that can vary with all other dimensions held constant; multidimensioned stimuli can have more than one stimulus dimension vary independently.

[^11]:    * As exemplified by recent billboard control legislation for the Interstate system.

[^12]:    * Assuming that every licensed driver will meet the listed minimum state licensing requirements. Because of the prevalence of "grandfather clause" licenses and physiological deterioration since the first issuance of a license, this assumption is, at best, an optimistic approximation.
    ${ }^{* *}$ It is difficult, although not impossible, as shown in the selection of military and commercial pilots and astronauts.

[^13]:    * A detailed case study analysis, showing how application of these principles to the presentation of macroperformance information would result in changes in current practices, is presented in Appendix E .
    ** See Appendix $B$ for a full description of these activities.

[^14]:    * Appendix A describes the equipment and the analytic techniques dedeveloped and used.

[^15]:    *The frame-by-frame data reduction of the filmed record of less than 20 miles of highway (one direction only) took almost 3 man-months.

[^16]:    * A tradernark of 3M Company.

[^17]:    * Standard size refers to sizes normally commercially available, for both cut-out and demountable letters. These are also the sizes listed in the Standard Alphabets (47).

[^18]:    * Because visual acuity is a function of the angle subtended by the smallest discernible detail and because at those small angles tangents vary linearly with angles, a straight-line relationship between acuity and letter height is assumed:
    ** It should be noted that these revised values have been computed without considering the effect of the unavoidable increase in sign panel size. The actual letter height would, therefore, be still higher.

[^19]:    *The legal minimum visual requirement for obtaining a driver's license in three states.

[^20]:    ${ }^{\mathrm{a}}$ To the right.

[^21]:    *This is not specifically stated in the report but assumed in the absence of contradictory information.

[^22]:    * A survey made in 1967 (94) showed compliance with the manual ranging from a low of 32 percent on non-Federal-aid county roads to 98 percent on the Interstate system.

[^23]:    * For example: stop ahead (situational ARI) implies cross road ahead (micro and situational road) and cross traffic ahead (situational traffic).

[^24]:    * This is especially true of four-way stop control. For instance, analysis of the Illinois Manual (95), which is representative of state manuals in general, reveals that "proper" use of this type of control, in most cases, implies an average cross-street volume of between 200 and 400 vph.
    ** In the example cited, repeated misapplication of stop control will lead to increased nonobservance, resulting in potential accidents (a catastrophic failure of the system).

[^25]:    * The statutory requirement, in some jurisdictions, for the display of this type of information to lay the proper legal groundwork for prosecution and conviction of violators is not discussed here.
    ** For two-lane roads. The message keep to right when passing is common on multilane highways.

[^26]:    * A similar approach in the United Kingdom is worthy of note in this connection. The final report on Motorway Signs (97) includes the following statement:
    "65. Finally, however, we should stress our view that the presence at every point of access to the motorways of signs setting out the Regulations, which must of necessity be wordy, should not be contemplated as a permanent feature. We think that every effort should be made to ensure that these rules and regulations become part of the general knowledge of the motoring public, so that the mere indication of a motorway, by either word or symbol, will carry with it all the necessary implications. We are glad to note that to this end an addition to the Highway Code has been prepared which deals in detail with the use of the motorways."
    ** The term "motorway" is used in England with the same meaning as the U.S. term "freeway."
    *** Illustrative examples can be found in Refs. 99, 100, 101.

[^27]:    * When official state maps are ordered from commercial map makers, they are often printed from the same masters as oil-company maps.

[^28]:    * Personal communication.
    ** To supplement his article, Mr. Usborne furnished examples of this material to the researchers, with a quantitative description of the publicity effort.

[^29]:    * In 1965, the total population of Great Britain was 54 million and total motor-vehicle registration was 12.9 million (105).

[^30]:    * Information on the AAA's mapping practices was furnished by Jack Boysan, Chief, Cartographic Division.

[^31]:    * By H. Lunenfeld and G. J. Alexander.

[^32]:    * By G. F. King.

[^33]:    * See especially the section, "Application of Computer Program," and Table 16.

[^34]:    * By G. Newberg, V. C. Lee, and H. W. Loewenstein.
    ** As presently constituted, the program can handle any combination of horizontal and vertical curvature. It cannot handle spirals or other transition curves that must be approximated by circular curves. It also cannot handle crown or superelevation.

[^35]:    *IBM Civil Engineering Geometric Program available on many computers and time-sharing systems.

[^36]:    * Due to their length, Figure C-8 and Table C-3 are not published herein; however, they are available on request to the Program Director, NCHRP.
    ** Due to their limited use, Figures C-9 through C-17 are not published herein; however, they are available on request to the Program Director, NCHRP.

[^37]:    * Figures C-21 through C-35 are not published herein; however, they are available on request to the Program Director, NCHRP.

    Individual card images are: Fig. 21, Horizontal alignment; Fig. 22, Profile; Fig. 23, Table of signs; Fig. 24, Specifications of vehicle and driver; Fig. 25, Vehicle location on road; Fig. 26, Compute; Fig. 27, Dump program input variables; Fig. 28, Heading; Fig. 29, End of job; Fig. 30, Modification to existing program variables in storage; Fig. 31, Eject; Fig. 32, Comments; Fig. 33, Restart; Fig. 34, Clear critical error and detailed output required; Fig. 35, Time interval request.

[^38]:    * By G. F. King.

[^39]:    * By G. F. King.

[^40]:    * There is no way of determining the actual number of possible destinations. An index to the magnitude of this number may be found in the fact that almost 20,000 different entries are found in the Statistical Abstract tabulation of "Places by Size."

[^41]:    * Belt (circumferential) roads, discussed later, are a conspicious exception.
    ** Similiarly, the Maine Highway Department has reported some difficulties with motorists driving to Portland avoiding the proper exit, signed "souTh-Portland," by reasoning that they did not want to go to South Portland, a well-known suburb.

[^42]:    * The idea that different directions of travel should be designated differently, for purposes of direction guidance and orientation, was first suggested to the researchers by Prof. S. M. Breuning.

[^43]:    * Private communications from Dr. R. D. Worall of Northwestern University and from Drs. W. W. Mosher, Jr., and A. D. May, Jr., of the University of California.

[^44]:    *See "Blockage of Signs by Trucks," in Part I of this report.

[^45]:    * For instance, New York appends the letters N and S (or E and W ) to the interchange number to denote the cardinal direction in which traffic would be heading after using a specific exit of a multiexit interchange.

[^46]:    * In the AASHO system, this presupposes that only one of the expressways meeting at this interchange is on the Interstate system. However, as long as even one approach to the interchange is not on the Interstate system there will be a number-no number dichotomy, depending on direction of approach.

[^47]:    * This does not apply to interchanges and ramps not open to the general public such as roadways leading to maintenance sites and police facilities. These, however, should be clearly identified so that their omission from the numbering system is self-evident.
    ** A continuous comprehensive transportation plan in accordance with Section 701 of the Housing Act of 1954, as amended, is a prerequisite for federal highway and mass transportation grants.

[^48]:    * The question of defining availability in terms of distance from exit, hours of operation, and quality standards is discussed, at length, elsewhere. See Kuprijanow et al. (E-15).

[^49]:    * By A. Kuprijanow and G. F. King.

[^50]:    * Signal 7J(65), "Criteria for 12-Inch Diameter Lens Signal."

[^51]:    * Except for occasional transmissions between two vehicles proceeding at the same velocity.

[^52]:    * The use of extruded thermoplastic material for pavement markings in recent years has greatly extended the service life of such markings.

[^53]:    * It may be twice (with a two-sided mirror), or three times, or . any number; for example, 8 times, with an octagonal mirror. Thus, more than one measurement per revolution is obtained and the rotational speed of the device may be reduced.
    ** By the researchers, first under NCHRP Project 3-4 (F-27) and in subsequent studies. In fact, a ranging device on the use of infrared emitting diode and a corresponding sensor have been developed experimentally, and "breadboard" units have been built and tested. Also, the ability of the human operator to respond to baselines of varying lengths has been investigated ( $F-28$ ).

[^54]:    * An 8 -cylinder engine, 4 cycle, at $2,000 \mathrm{rpm}$ will produce a noise frequency of 132 cps -assuming no suppression on a cylinder-by-cylinder basis.

[^55]:    * A sequence of several successive flashes is allowed to decrease the probability of false alarms (spurious signals) that might result from reflections, sweeping the beam over the detector, lightning, etc.

[^56]:    * Considerations of relative and absolute tone deafness, especially in older drivers, combined with a high ambient noise level, would result in a severely restricted alphabet.

[^57]:    * Coherence means that throughout the cross section of a beam of light. or at every point of an undisturbed wavefront moving from a source, all the parts of the beam are in phase.

[^58]:    * This appendix was prepared in 1967 and the information contained therein is current as of that date. By R. Luke and G. J. Alexander.

[^59]:    * By H. Lunenfeld and G. F. King

[^60]:    * However, it is recommended that users refer to other parts of this report for a detailed description and discussion of the findings herein.

[^61]:    * See Chapter Two of this appendix for a definition and discussion of the principles referenced in this chapter.

[^62]:    * Assumes a $20 / 20$ visual acuity for drivers.

[^63]:    * The 85 percentile speed is recommended for converting driving time into road distance.

