DEVELOPMENT OF A METHODOLOGY FOR EVALUATING ROAD SIGNS

by

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PREFACE

This report presents the findings of a two and one-half year research project in developing a methodology for evaluating road signs by using an eye-marker camera system as a primary research tool. This project was sponsored by the Ohio Department of Highways and the Federal Highway Administration.

The research was conducted in two stages, namely, Stage A and B. Each stage included three phases. The six phases were as follows:

Phase A-I:	The Development of Assessment Techniques for Distinguishing Signing Differences,
Phase A-II:	Testing of Assessment Techniques,
Phase A-III:	Application of the Assessment Techniques for the Purposes of Evaluating "Ongoing" Sign Changes Made by the Ohio Department of Highways on I-90 in Cleveland,
Phase B-I:	Expansion of the Scope of the Methodology for the Evaluating of Road Signs,
Phase B-II:	Increasing the Sensitivity of the Methodology, and
Phase B-III:	Continued Evaluation of Existing Highway Signing.

This report includes results of a series of eight field studies and three laboratory studies conducted to fulfill the objectives of this research. For the computation of the measures developed for the Evaluation of Road Signs, two computer programs called SEADEM I and II were developed for the Analysis of Driver Eye-Movement Data collected under actual driving situations. This report also presents the description of the SEADEM computer programs.

The research findings obtained from this project are currently being further developed under another research contract entitled, "Implementing Sign Research Into Operational Practices," (Project EES 407B) sponsored by the Ohio Department of Highways and the Federal Highway Administration.

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Although it is impossible to adequately recognize and credit each individual that assisted in performing the research presented in this report, the following people must be singled out because of their major contributions. Dr. Robert R. Safford actively participated in directing and assisting in the research work conducted in the first three phases of this research. Messrs. Jeff Powell, George Taylor, and Robert Ploetz participated in the experimental work in this study. Mr. Thomas Gueth must be praised for his creative computer work in developing SEADEM II computer program. Both Messers. Clarence James and Larry Tracewell deserve credit for the fabrication and maintenance of the instrumentation used in this research. Ms. Sharon Mays and Mrs. Lois Graber must be commended for their efforts and patience in the final preparation of this report.

The Systems Research Group would like to thank the Ohio Department of Highways Sign Shop for their assistance in manufacturing the signs used in some of the studies. The Systems Research Group would like to also thank the personnel of the Ohio Department of Highways for their assistance in obtaining necessary information and advice at various stages of this research. Special thanks are due to Mr. Thomas Foody of the Ohio Department of Highways for his cooperation and advice on the many occasions for which it was requested.

ABSTRACT

The objective of this research was to develop a methodology that will enable the evaluation of road signs by using an eye-marker camera as a primary research tool. The methodology developed in this research attempts to evaluate a road sign by determining the degree of match between the sign reading behaviors of the drivers and the characteristics of the signs, and highway and the traffic situations.

In this research eight different field studies and three laboratory studies were conducted to determine the effects of different variables that are related to the characteristics of the signing, the drivers, the highways and the traffic situations on the sign reading behaviors of the drivers. The field work involved collection of the driver eye movements and driver performance data under actual driving situations for over 400 different interstate highway signs during daytime using an average three to five subjects. The data was analyzed by specially developed computer programs called SEADEM programs (Sign Evaluation by the Analysis of Driver Eye Movements). The SEADEM computer programs analyzed the data and computed sign evaluation measures describing sign reading behaviors of the drivers. Further analyses of the sign evaluation measures showed that the measures were related to many different factors associated with the characteristics of the signing, the driver, the highways, and the traffic situations. The understanding into how various different factors influence the sign reading behaviors of the drivers provides a basis for the implementation of the methodology for both the evaluation and the design of highway signing.

Some of the most important results obtained from this research are as follows:

1. The maximum time-distance from which a driver actually begins to acquire information from a sign is the "key" variable for both the design and the evaluation of signs. The above time-distance decreases with increase in visual loads caused by increase in traffic density.

2. In general, the drivers do not concentrate on the sign after the first fixation on the sign, but they time-share with the sign and other objects on the road. The time-sharing process of the drivers with the sign is dependent upon factors such as time-distance to the first fixation on the sign, traffic density, type of informational need of the driver, length of message displayed on the sign, relevancy of information to the driver, driver familiarity, etc.

3. The sign reading behaviors of drivers driving on unfamiliar roads under "confusing" and "inadequate" signing situations, in general, exhibit the following characteristics:

   a. late beginning of sign reading; i.e., very low utilization of legibility distances,

   b. concentrated attention on signs during time-sharing interval, and

   c. late completion of sign reading; i.e., continued reading as late as possible until the sign is passed.

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LIST OF SYMBOLS

T_{max}	=	maximum time-distance (in seconds) from which information displayed by the largest letter (letter size) or symbol on the sign can be read
T_f	=	time-distance (in seconds) at the beginning of the first fixation when the largest letter or symbol on the sign forms a resolvable image on the retina of the approaching driver
T_e	=	time-distance (in seconds) at the last fixation when a letter of symbol on the signs forms a resolvable image on the driver's retina
T_i	=	$(T_f - T_e)$ = time in which perceptual time is shared with the sign and the tasks in driving
T_{used}	=	total time (in seconds) during which information displayed by the sign forms a resolvable image on the driver's retina (This represents total time available to the driver for obtaining information from a sign.)
T_{reqd}	=	minimum time (in seconds) required to acquire the required information from the message displayed on the sign
T_{eblr}	=	minimum possible value of T_e (defined such that from the time distances below T_{eblr} a sign cannot present resolvable information to a driver)
T_{max}/T_f	=	sign information availability utilization and urgency indicator ratio
T_i/T_{used}	=	sign information sampling index
T_{max}/T_{used}	=	sign information utilization ratio
T_{max}/T_{reqd}	=	sign design evaluation criterion ratio
T_{used}/T_{reqd}	=	visual load indicator ratio
T_{max}/T_i	=	sign reading and time-sharing index
t	=	time-distance of the driver from the location of the sign (measured in seconds)

$[\sigma(t), \Psi(t)]$	=	angular location of the eye fixation (or visual axes) of the driver at time-distance t from the sign (measured in degrees with focus of expansion considered as the origin (Note: Focus of expansion is defined as a point in the driver's visual field from where the driver's dynamic view appears to expand. It is approximately at the location of a far-point where the two lane markers seem to meet.)
$[\theta_i(t), \phi_i(t)]$	=	angular location of the i^{th} point on the sign at time t (measured in degrees from the focus of expansion as the orgin)
i	=	Note: i = 1 denotes center of the sign i = 2 denotes a mid-point on the left edge of the sign i = 3 denotes the mid-point on the right edge of the sign
$\eta_i(t)$	=	eccentricity angle of the sign at the i^{th} point on the sign at time t (Note: Eccentricity angle is defined as the angle between the visual axis and the ith point.)
$\alpha[\eta_i(t)]$	=	resolution angle measured in minutes of arc in the driver's visual field at eccentricity angle $\eta_i(t)$
$\gamma_i(t)$	=	angle subtended by the largest sized letter on the sign at the cyclopean eye position of the driver
x(t)	=	longitudinal distance of the driver from the sign at time t (measured in feet)
K_1	=	number of longitudinal location of the sign; i.e., number of the sign location in the sequence of sign (Note: $K_1 = 1$ denotes the farthest sign location from the exit
K_2	=	position of the sign (measured from left to right) in a group of multiple signs at a location (For example, if there are three signs at a location $K_2 = 1$ denotes the left sign; i.e., above the left lane; $K_2 = 2$ denotes the sign at the center and $K_2 = 3$ denotes the sign at the right
K_0*	=	critical value of T_{max} selected for the design or evaluation of a sign
K_1*	=	critical value of T_{max}/T_f selected for the design or evaluation of a sign

K_2*	=	critical value of T_{used} selected for the design or evaluation of a sign (This value would be a suitable percentile value of T_{reqd}.)
K_3*	=	critical value of the ratio $(T_f - T_{eblr})/T_{reqd}$ selected for the design or evaluation of a sign
K_4*	=	critical value of the ratio T_i/T_{used} selected for the design or evaluation of a sign
NR	=	denotes signs that present information "Not Relevant" to the driver in following intended route or destination
NP	=	denotes signs that present information relevant but "Not Pertaining" to the driver in following intended route or destination
PR	=	dentoes signs that present information relevant and pertaining to the driver in following intended route or destination
IN1	=	informational need of Type I: searching for milage number for a given destination from a sign
IN2	=	informational need of Type II: searching for a given destination when it was displayed on the sign along with other destinations
IN3	=	informational need of Type III: searching for a given destination when it was not displayed on the sign
W	=	number of words per line displayed on a sign
L	=	number of lines of messages displayed on the sign
F	=	level of driver familiarity with the sign (or highway)
P	=	line position of the required message displayed on the sign level
p	=	significance level (probability of rejecting the null hypothesis is when it is true in a statistical test)
ρ	=	correlation coefficient

Chapter I

SUMMARY OF THE RESEARCH

Introduction

Since January, 1968, the Systems Research Group has been engaged in the research on highway signing. The primary aim of this research project was to develop a methodology for evaluating road signs by using an eye-marker camera as a primary research tool. In this research, eye movements of drivers were recorded under different actual driving situations and data on driver eye movements and driver performance was collected for over 400 different interstate highway signs using an average of three to five subjects in different experiments. For field data collection an instrumented vehicle was used. The instrumented vehicle was designed such that simultaneous synchronized data on driver eye movements and driving performance could be recorded.

The majority of driver eye movements in this research were collected under experimental conditions such that the subject drivers were totally unaware of the objective of this research. The drivers under field studies were only given freeway entering and exiting instructions and nothing was mentioned to them about the signing. The collection of driver eye-movement data, thus, enabled the researcher to obtain unbiased (instruction free) sign reading behaviors of drivers over time. Some of the experiments in this research included testing under controlled situations where specially designed research signs were erected and employed with the cooperation of the Ohio Department of Highways. The research was further supplemented by conducting some laboratory experiments for investigation of some effects and hypotheses which are described later in detail.

Objectives of the Study

This research project began in January, 1968, with three primary research objectives which can be described by considering the following three phases.

Phase A-I:	The Development of Assessment Techniques for Distinguishing Signing Differences: This phase of the research relied upon the analysis of driver performance data collected on urban and rural freeways to indicate the performance variables that reflected differences in signing quality.

Phase A-II: Testing of Assessment Techniques: Controlled experimental studies conducted with specially erected signs were used to evaluate the assessment techniques developed in Phase A-I of the research.

Phase A-III: Application of the Assessment Techniques for Purposes of Evaluating "Ongoing" Sign Changes Made by the Ohio Department of Highways: Subjects were extensively tested before and after major signing changes on an eight-mile stretch of the Memorial Shoreway (Interstate 90) in Cleveland, Ohio.

The research on the above three phases was conducted primarily in the period between January, 1968, and June, 1970. On the basis of the research findings in the above research phases, a proposal for continuation of this research was submitted to the Ohio Department of Highways in April, 1970, and research was continued from August, 1970. In the continuation of this contract, in addition to continuing research on the above three phases, the following three new phases were added.

Phase B-I: Expansion of the Scope of the Methodology: The direction considered for the expansion of the scope of the methodology was to study its evaluation capabilities in investigating effects of multiple and sequential signing under effects of visual load. (Note: The term "multiple signs" refers to installations having more than one sign at a longitudinal location on the highway. The term "sequential signs" refers to sequence of signs presenting similar information; e.g., signs for exits presenting information before: one mile, one half mile, and just before "Next Right.")

Phase B-II: Increasing the Sensitivity of the Methodology: Two directions were considered for this purpose:

i. to incorporate exact highway geometry for the analysis of driver eye-movement data (Note: This was accomplished by developing new computer programs SEADEM II. See Chapter III.), and

ii. to estimate T_{reqd} and investigate the effects of variables affecting T_{reqd}. (Note: T_{reqd} is defined as minimum time required to acquire required information from the sign.)

Phase B-III: Continued Evaluation of Existing Highway Signing: The sites considered for this purpose were categorized in the following manner:

i. signs presenting information contradictory to geometric highway design; e.g., signing requiring a turn to south in order to eventually end up going north,

ii. "confusing signing:" signs which are generally regarded as confusing; e.g., signing that "contradicts" a performance stereotype; left hand exits, and

iii. diagrammatic signing.

Figure 1.1 presents a flow diagram showing the relationship of important research activities conducted in this project to the six research phases described earlier. The experimental work included eight field studies (number F-1 to F-8) and three laboratory studies (number L-1 to L-3). All the studies shown in this figure are described briefly on pages 17 to 19.

It should be noted that all the research work performed prior to June 1970, was described in detail in the interim report of this project. The final report is, therefore, primarily written to cover all the research work that was undertaken after the interim report was submitted. However, in preparing this report, attempts have been made such that it can be read independently without the help of the interim report. But for more details on the research prior to June 1970, the interested reader is suggested to refer to the interim report.

Research Rationale

The rationale underlying this research is of a different nature than the majority of the researches reported in the literature related to design, improvement and evaluation of road signs. The reported researches in this area are primarily conducted in determining effects of the following factors:

1. factors determining legibility distances; e.g., contrast of letters, height of letters, stroke width, etc., and

2. visibility factors related to detection of a sign ("target value" or "attention value" of a sign); e.g., area of sign, color, brightness contrast with background, etc.

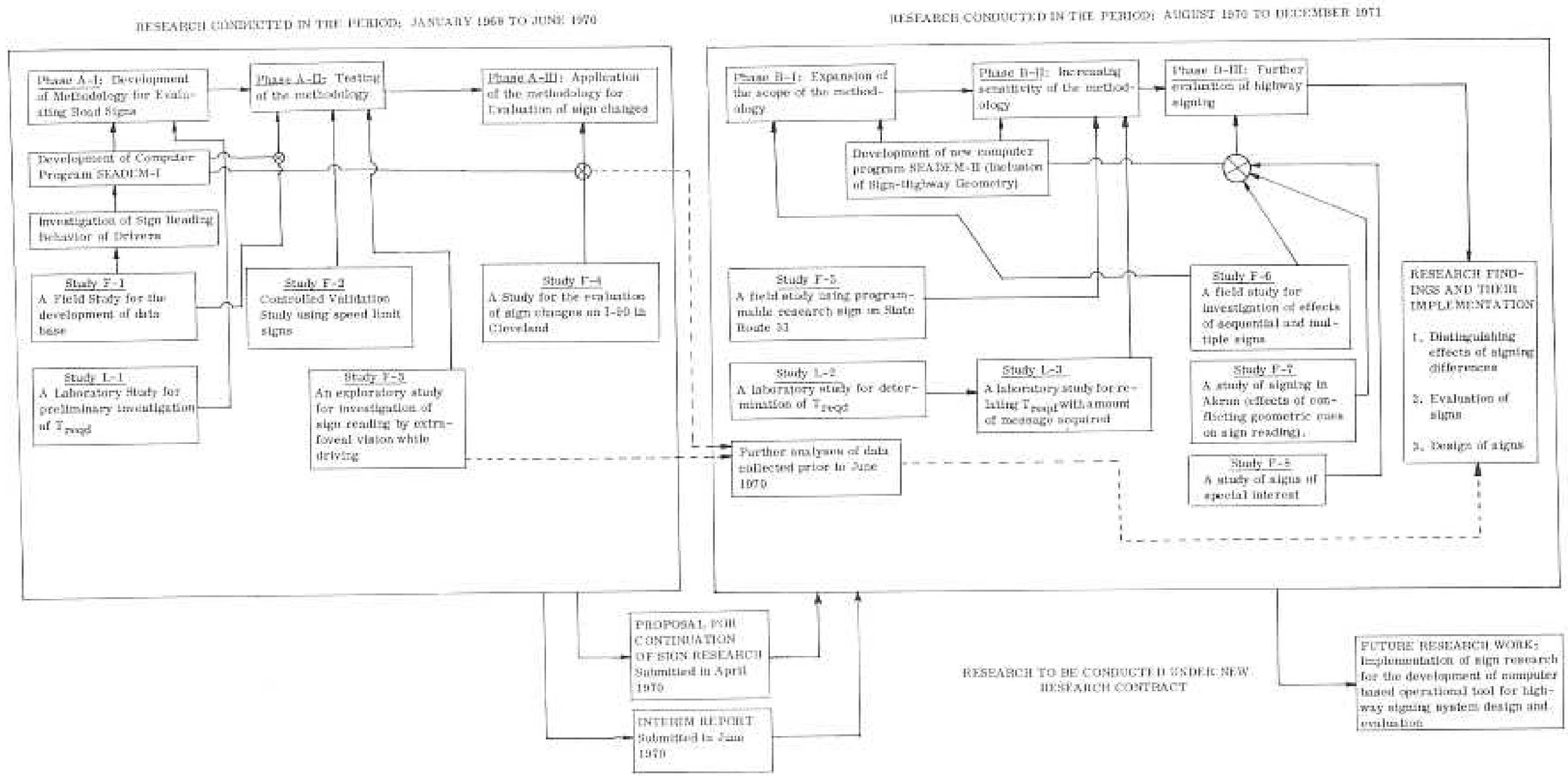


Figure 1.1.--Flow Diagram of Research Activities of Sign Evaluation Research

The implementation of results obtained from the studies on factors such as those presented above are generally not clear when actual driving situations are considered. This is primarily due to the fact that the majority of such researches have been conducted under laboratory conditions where the driving task is either totally absent or not considered in a truly realistic manner.

In general, the literature review in this research area suggests that almost no attention has been given to the problems of determining how a driver acquires information from a sign. More specifically, questions such as: when does a driver actively start reading a sign, when does he stop reading, and how does he time-share with a sign and other driving tasks, are unanswered.

The primary emphasis in conducting this research was, therefore, to study sign reading behaviors of drivers from a sign information acquisition-processing viewpoint, and to develop an assessment technique for the evaluation of road signs.

While driving, a driver acts as an information processing device which constantly acquires information, primarily through visual senses, and provides controlling actions to maintain lateral and longitudinal control of his vehicle on the highway. A driver cannot attend equally and simultaneously to all the visual cues available to him through the windshield of his vehicle, due primarily to physiological limitations of the human retina, maintenance of perceptual characteristics of the binocular vision (Yarbus, 1967), and the human information processing capabilities. He, therefore, must sample the visual environment and time-share between various regions and objects in his visual field to obtain visual information necessary to perform the driving task. The driver eye movements recorded while driving give important information on the temporal and spatial characteristics of the visual sampling behavior of drivers.

The human eye makes different types of movements. A detailed description on the types of eye movements can be found in Yarbus (1967). While driving, the majority of driver eye movements consist of discrete "eye fixations" linked by continuous movements; i.e., saccades of high velocity. An eye fixation can be defined as an apparent stationary position of the eyes between two successive eye movements. A driver can extract information from the optical image on his retinas only in a fixation (Yarbus, 1967). The durations of the fixations while driving generally range between 100 to 600 milliseconds.

An eye movement system that works on the principle of corneal reflection was used in this research. The system essentially records superimposed images of the position of driver's visual axis and the driver's forward visual scene encompassing $20^{\circ} \times 20^{\circ}$ visual field on 16 mm film. A detailed description of the eye-marker camera system is presented in Appendix B.

Figure 1.2 presents a series of pictures illustrating where a driver looks as he approaches and passes a sign location. The series of pictures shown in

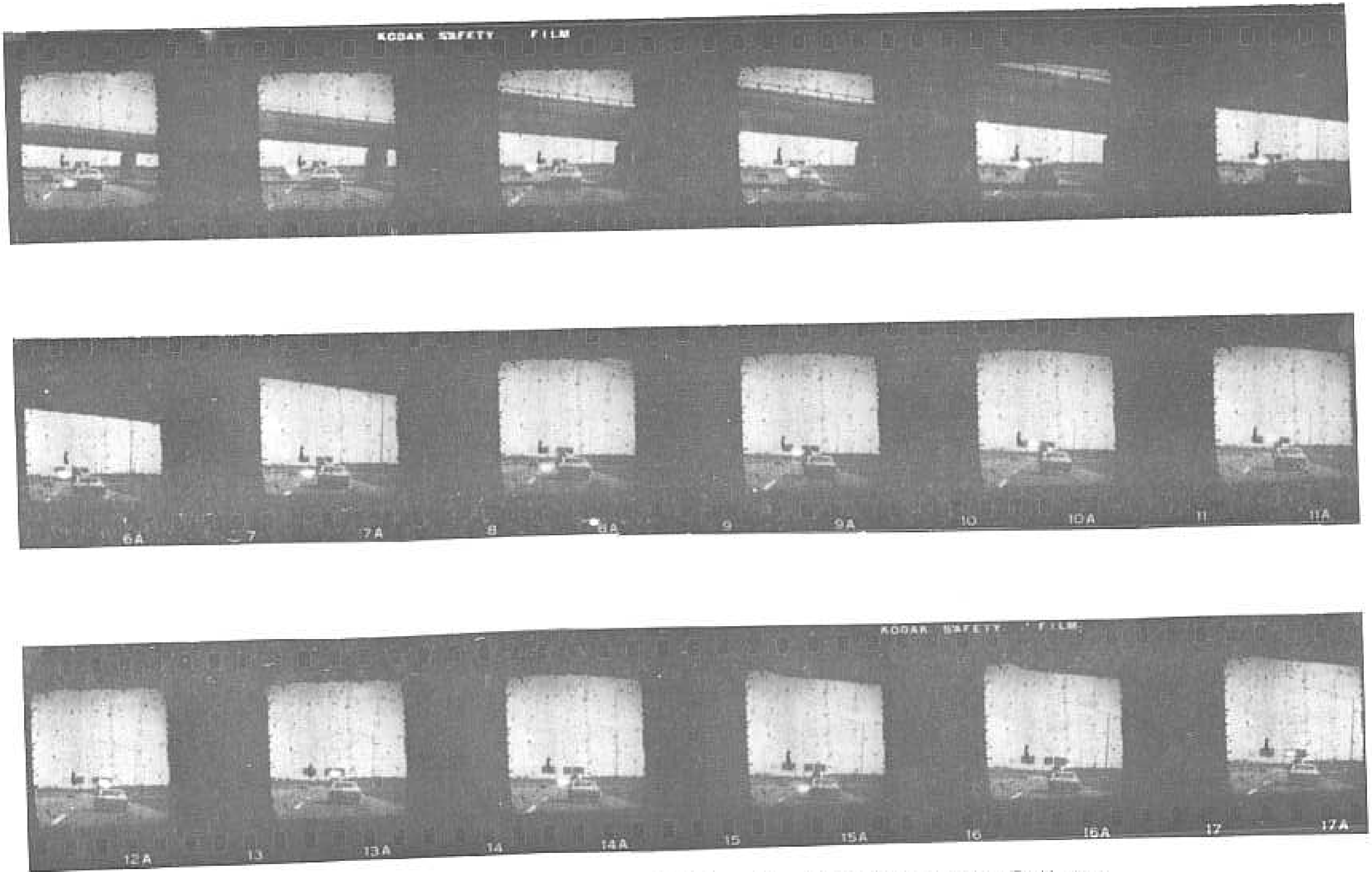


Figure 1.2.--An Illustration of Driver Eye Search and Scan Patterns While Approaching and Passing a Sign Location

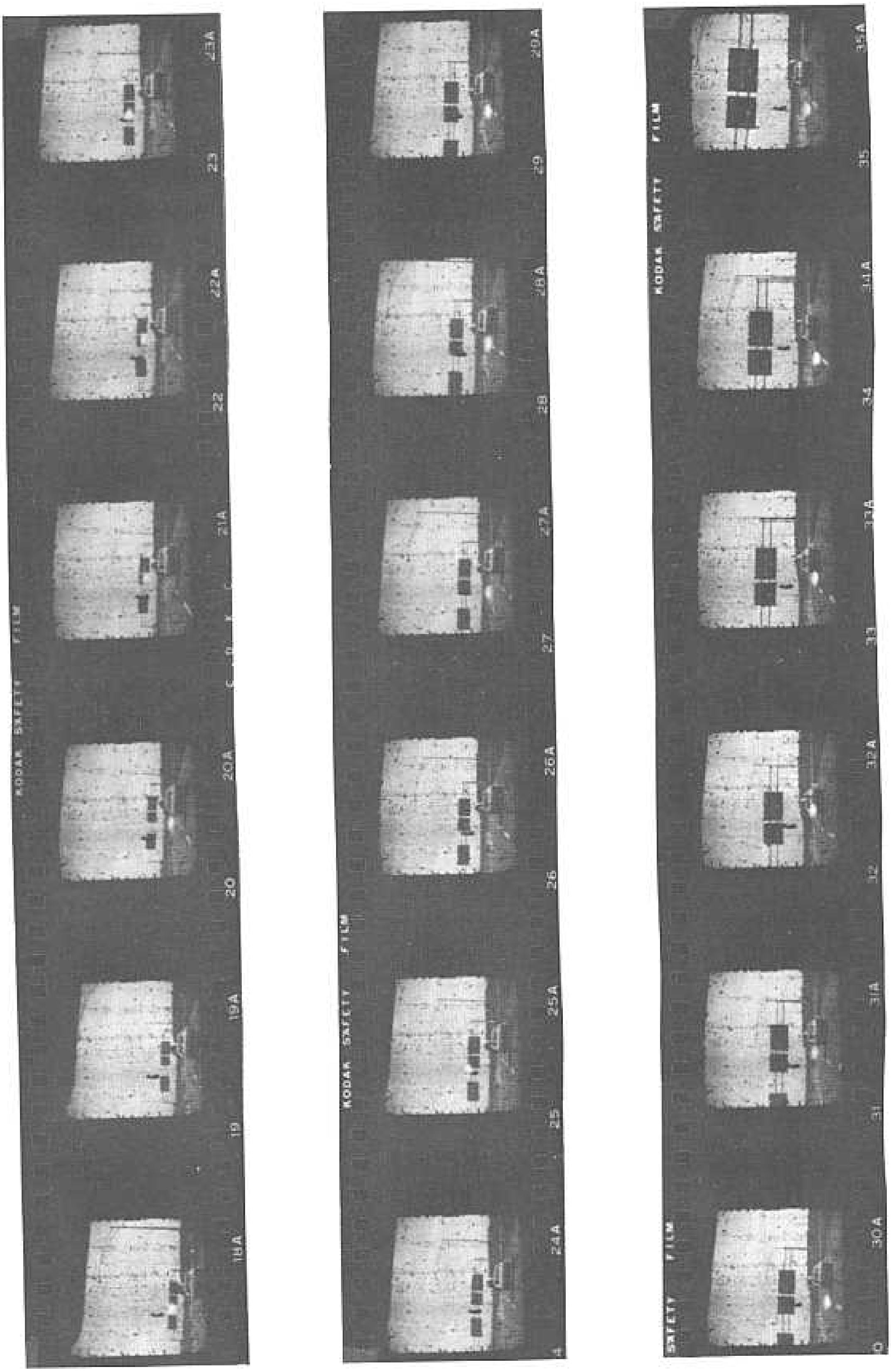


Figure 1.2.--(Continued)

Figure 1.2 were obtained by sampling frames from a 16 mm driver eye-movement film (obtained at 16 frames/second speed) at the beginning of every successive fixation. It should be noted that in each of the pictures presented in Figure 1.2 the white spot (usually called the "eye spot") indicates the location of the driver's eye fixation (or the visual axis). Further, the pictures (Figure 1.2) in which the eye spot does not appear on the film indicates that the driver was either looking (i.e., fixating) at objects outside the $20^{0} \times 20^{0}$ field of the camera scene lens or the driver was blinking.

The experimental work of this research began with Field Study F-1 which was primarily conducted to gain an understanding into the problem of studying sign reading behaviors of drivers. The preliminary investigations (on the data obtained in Study F-1) made by analyzing the fixations that the drivers make on signs show that there exist wide individual differences. Some drivers tend to stare at the signs for a considerably longer time than the minimum time that they would require to read the message displayed by the signs; whereas, other drivers, even on totally unfamiliar sections of highways, do not make any direct fixations on the signs that are relevant to exiting instructions, but, rather use extra-foveal visual processes.

The possibility of drivers acquiring information by extra-foveal vision was further investigated by conducting controlled experimental runs in Field Study F-3. The results, in general, showed that a driver could obtain information from a sign if the image of the sign formed on the driver's retina presents resolvable information. Therefore, it was found to be necessary to analyze the fixations made close to the signs to consider the possibility of sign reading by drivers by using their extra-foveal vision.

On the basis of results of Field Study F-1, the methodology for evaluation of road signs was developed. The assumptions used in developing the methodology were later tested by conducting field studies numbered F-2 and F-3. The field study numbered F-5 and the three laboratory studies (numbered L-1 to L-3) were conducted to investigate effects of different independent variables on one of the important variables, T_{reqd}, which is defined as the minimum time required for a driver to acquire required information from a sign.

The remaining field studies reported herein were conducted either for the purposes of the enrichment of the methodology or for the evaluation of signing situations of special interest. A more detailed description of the experimental work is presented on pages 77 to 204.

A Brief Description of the Methodology

The approach taken in developing the methodology is that of a simple visual information transfer between the traffic sign (visual information display source) and the driver.

The methodology attempts to determine the degree of a "match" between the source of information, the sign, and the moving receiver on the road (i.e., the driver) in terms of the adequacy of the information displayed by the sign in relation to the receiver's visual sampling behavior (i.e., the sign reading behavior) obtained by using an eye-marker camera system.

The sign reading behavior of the driver can be defined as the visual behavior of the driver that is responsible for acquiring the information displayed by the sign. The eye movements of the driver while approaching a sign constitutes only one of the variables that is needed in understanding how a driver acquires the information from the sign. More specifically, in order to evaluate whether a driver can or actually acquires the information, the consideration of the following factors is needed:

1. sign related characteristics

    a. location of the sign with respect to the highway,

        i. distance of the left edge of the sign from the right edge marker of the highway, and

        ii. height of the lower edge of the sign from the surface of the road,

    b. size of the sign,

    c. sizes of letters and symbols,

    d. geometric perspective of the highway before a driver passes the sign,

    e. length of the message on the sign,

    f. multiple signs, and

    g. sequence of signs,

2. driver related characteristics

    a. visual acuity in the visual field of the driver,

b. path of motion of the vehicle with respect to the sign,

c. vehicle speed,

d. time available for the driver to assimilate and process the information available and to interpret the message displayed on the sign,

e. complexity and familiarity of the message, and

f. relevancy of message with respect to driver objectives, and

3. <u>highway and traffic related characteristics</u>

situational visual and information processing loads on the driver due to factors such as traffic density, highway design presenting conflicting geometric cues, etc.

The problem of measurement of sign reading behavior of the driver is, therefore, the same as the problem of measurement of fixations during which the driver acquires information from an oncoming sign. Further, the problem of determining the fixations in which a driver can and cannot obtain information from a sign is extremely complex. This is primarily because during the course of this research it was found that the driver need not make direct fixation on a sign (i.e., directly point their eyes or visual axis on the sign) but can obtain information from the sign from extra-foveal parts of their visual field provided the visual capability of the portion of the visual field where the image of the sign (i.e., the displayed message) forms is high enough to be resolved.

Therefore, the visual information displayed by a sign can be considered to be available to a driver only if the optical image of the sign formed on the driver's retinas while driving is "resolvable." The image of the sign can be considered to be resolvable only if the letters (or numbers, symbols, etc.) displayed on the sign form an image which is clear enough such that a driver with a given acuity can extract information when needed. In order to determine resolvability of letters on a sign in the driver's visual field, the following assumption is made:

> A letter (or number) on a sign is considered to form a "resolvable" image on a driver's retina if the angle (measured in minutes) subtended by the height of the letter (or number) is greater than or equal to 5.5 times the resolution angle (i.e., reciprocal of visual acuity) at that radial position (i.e., eccentricity) on the retina where the image of the letter is formed.

For a detailed discussion on the considerations involved in making the above assumption and the definition of visual acuity, an interested reader is referred to Rockwell, et al., (1970), LeGrand (1967), and Davson (1962). The above assumption was supported by conducting controlled field studies in this research. It should be noted that all the field studies in this research were conducted under daytime luminance levels ranging between 10 to 10^4 cd/m^2.

In order to determine the availability (or resolvability) of information displayed by a sign to a driver in successive eye fixations that a driver makes as he approaches a sign, a computer program, SEADEM, was developed. The program, SEADEM (Sign Evaluation by Analysis of Driver Eye Movements) requires the following inputs:

1. driver eye-movement data collected on the test section, (The eye-movement data consists of angular coordinates and durations of successive eye fixations made by the test driver as he approaches a sign.)

2. highway geometry,

3. velocity profile and the path (i.e., lane position) of the test vehicle on the test section of the highway,

4. sign characteristics (i.e., location of sign, sizes of letters, sign size, contrast, etc.), and

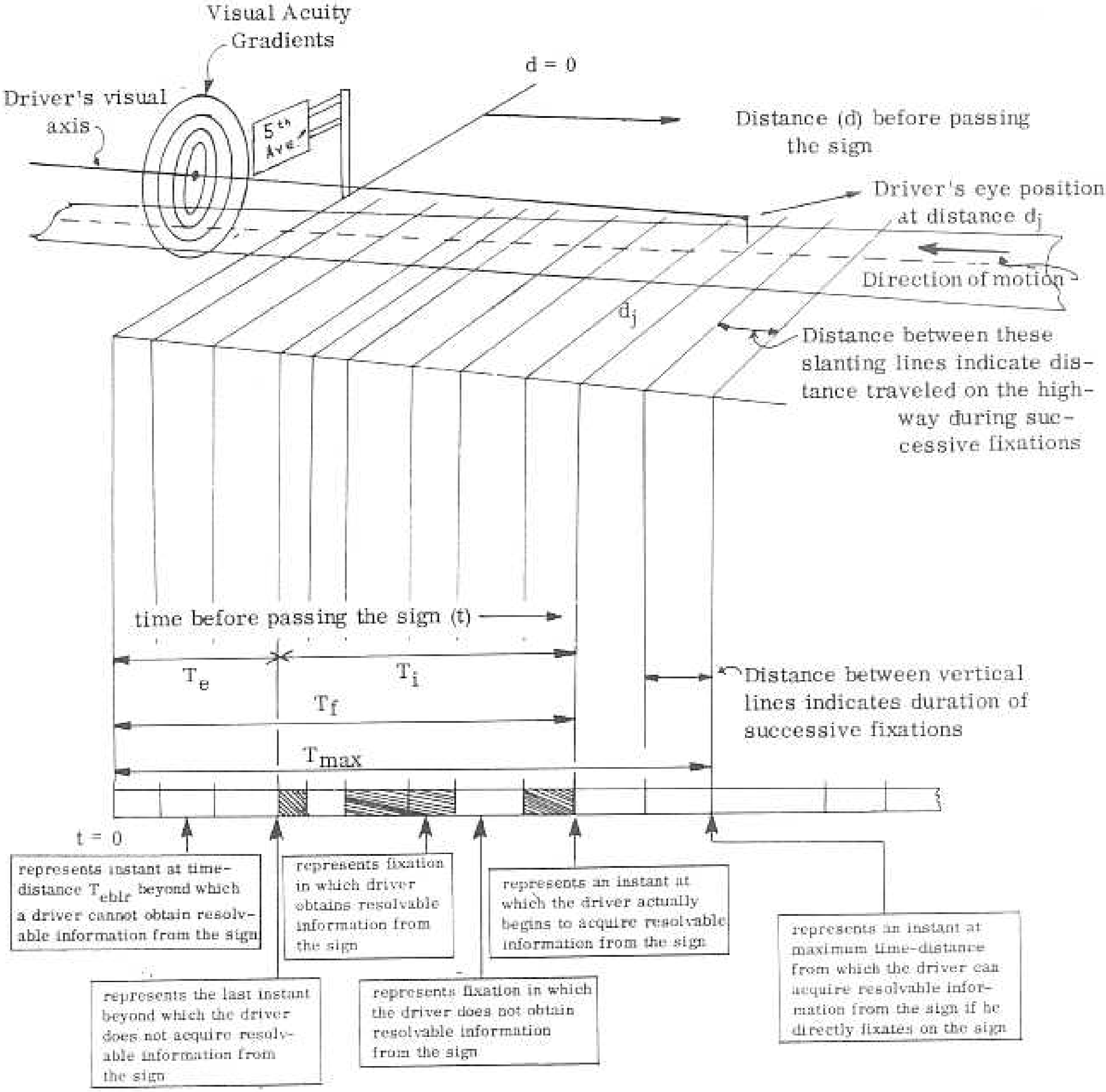
5. visual acuity in the binocular visual field of the test driver.

From the above inputs, SEADEM determines those eye fixations that provide resolvable information about the sign to the driver and then computes the following measures that are used to define the sign reading behavior of the driver (see Figure 1.3).

T_{max} = maximum time-distance during which information displayed by the largest letter or symbol on the sign can form a resolvable image on driver's retina if the driver were fixating foveally on the sign.

T_f = time-distance at the beginning of the first fixation when the largest letter (or number) on the sign forms a resolvable image on the driver's retina.

T_e = time-distance at the last fixation when a letter (or number) on the sign forms a resolvable image on the driver's retina.



Note: T_{used} = sum of durations of all fixations that provide the driver resolvable information from the sign to the driver (Note: These are shown in the above illustration by ▨ .)

Figure 1.3.--Sketch of a Highway Illustrating the Definition of the Measures Developed to Describe the Sign Reading Behavior of Drivers from their eye movements

T_i = $(T_f - T_e)$ = time interval in which perceptual time is shared with the sign and the tasks in driving.

T_{used} = total time during which information displayed by the sign forms a resolvable image on the driver's retina. (This represents total time available for obtaining information from a sign.)

T_{eblr} = minimum possible value of T_e (defined such that from the time distances below T_{eblr}, a sign cannot present resolvable information (i.e., blurred image) to a driver due due to limitation of driver's visual capabilities, angular position of the sign and the angular velocity of the sign in the driver's visual field).

In addition to the above measures another measure called T_{reqd} was defined as follows:

T_{reqd} = minimum time required for an unfamiliar driver to acquire information displayed by a sign.

For purposes of determining values and distributions of T_{reqd}, as a function of variables such as length of displayed message, type of informational need of the driver in relation to the message displayed by the sign, experiments were conducted. The measure T_{reqd} was defined primarily to enable comparison between the observed values of T_{used} and T_{reqd} for a same sign to investigate the problems related to partial or excessive sign reading by the drivers.

The above defined measures are functionally related to various factors such as sign characteristics, driver familiarity with the route, etc. A partial list of functional relationships can be briefly presented as follows:

T_{max} = f (size of letters, speed of vehicle, visual acuity, location of driver with respect to sign),

T_{used} = g (traffic characteristics, familiarity, complexity of message on the sign, highway geometry),

T_f = h (sign detection, urgency of information, traffic characteristics, visual acuity, height of largest letter),

T_e = k (complexity of message, familiarity, T_f, height of the largest letter, relevancy of message),

T_{eblr} = l (relative angular position of sign with respect to driver's path, velocity, visual acuity), and

T_{reqd} = m (complexity of message, familiarity, relevancy of message).

Figure 1.4 presents a schematic model showing how some of the basic factors and the decision making activities of the drivers could be related to the basic measures that are defined to describe the sign reading behaviors of the drivers. The model presented in Figure 1.4 is based on the following hypotheses:

1. The time-distance at the first fixation from which the driver begins to acquire information from a sign would be related to T_{max}. More specifically, it is hypothesized that the higher the value of T_{max}, the higher would be the value of T_f.

2. The measure T_f would be dependent upon the following factors:

   a. driver's informational need, and

   b. visual load on the driver's information acquisition and processing capacity due to other driving tasks.

   It was hypothesized that with an increase in driver urgency of information, the value of T_{max}/T_f would tend to move close to 1.0. Further, it is hypothesized that with increase in visual load (primarily due to traffic density) the value of T_{max}/T_f would increase.

3. The total time, T_{used}, during which a driver would obtain information from a sign would depend upon the following factors:

   a. $(T_f - T_{eblr})$ = total time available to the driver to obtain information from the sign,

   b. relevancy of information presented by the sign in relation to drivers informational need,

   c. amount of message presented on the sign, and

   d. visual information demands in performing other tasks in driving.

   It should be noted that the difference $(T_f - T_{eblr})$ defines the maximum time that is actually available for a driver. It is, therefore, hypothesized that, depending upon the informational need, the driver time-shares his visual attention (in the period $T_f - T_{eblr}$) between the sign and other

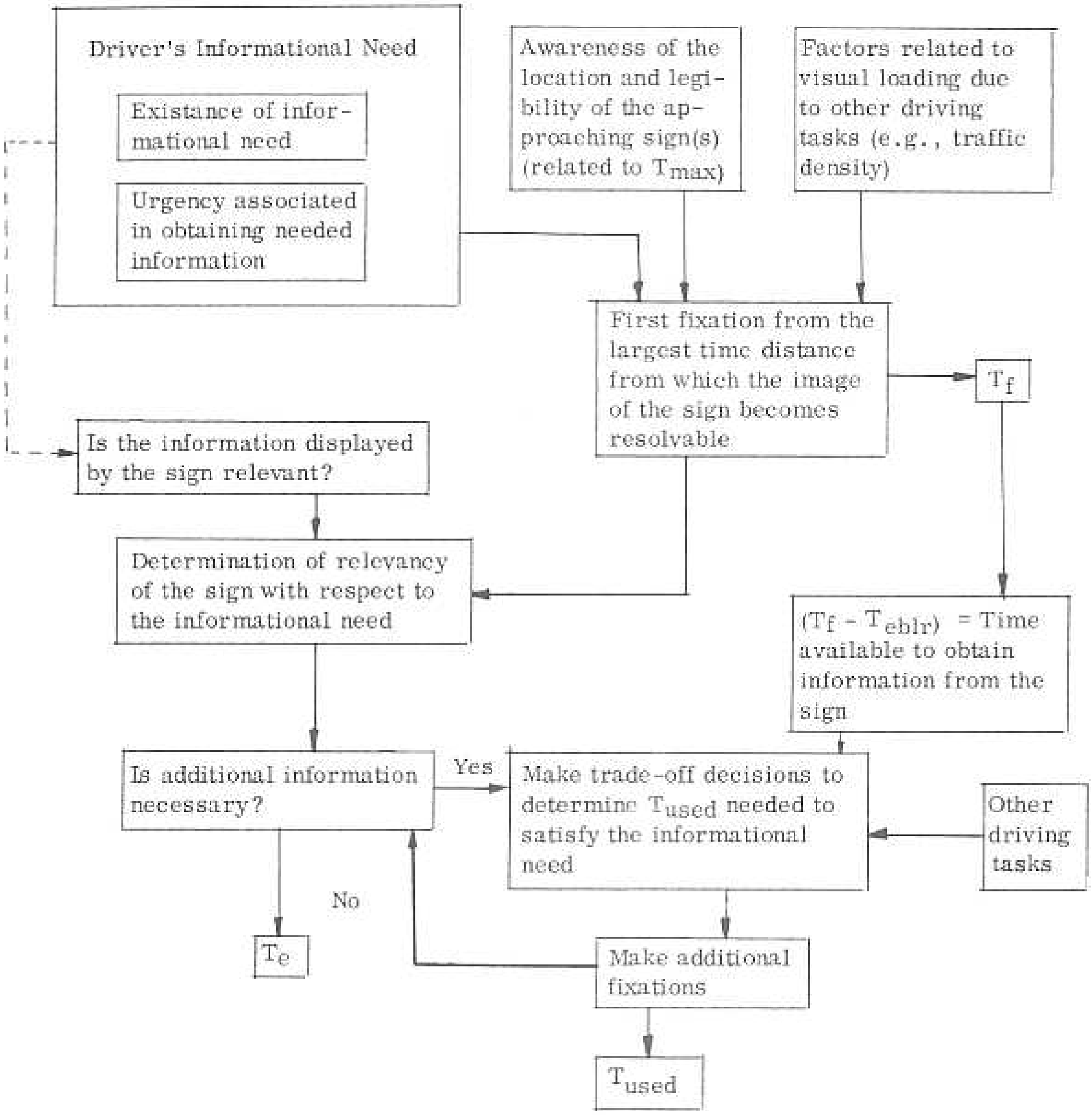


Figure 1.4.--Schematic Diagram Illustrating the Basic Factors Associated in the Decision Making Activities of the Drivers that Explain their Sign Reading Behavior

sources of information which provide him information necessary to perform other driving tasks. The time-sharing process is further hypothesized to be a trade-off type process where the driver has to make decisions on the following:

a. proportion of (T_f - T_{eblr}) time to be spent between acquiring information to perform other tasks in driving,

b. percentage of needed information to be acquired from a sign without interpretation errors, and

c. driver urgency associated in obtaining the information from a sign.

4. The ratio T_i/T_{used} is hypothesized to be a descriptor of the above mentioned trade-off process. The signs for which values of T_{used} are higher and the values of T_i/T_{used} are lower would then indicate driver's increased concentration on the signs. Therefore, it is hypothesized that the important criterion for determining "adequacy" of a sign would be as follows:

   a. T_{max}/T_f should be as small as possible. It should be noted that the time period (T_{max} - T_f) indicates unutilized time; i.e., a driver does not utilize the available information from the sign,

   b. values of the ratio ($[T_f - T_{eblr}]/T_{reqd}$) should be greater than or equal to T_i/T_{used}. It should be noted that T_{reqd} is defined as the time required by an unfamiliar driver to obtain the needed information with no interpretation errors. Further, if T_{reqd} is less than T_{used}, it would indicate that the driver did not obtain all the information adequately or he only read the sign partially.

Some Details Concerning the Experimentation

In order to fulfill the objectives of this study eight field studies and three laboratory studies were conducted. Tables 1.1 and 1.2 present some details concerning the field studies and the laboratory studies, respectively.

In all the eight field studies the data was collected by using an instrumented vehicle. The instrumented vehicle was equipped to record simultaneous synchronized data on driver eye movements and driving performance.

Table 1.1

Summary of Field Studies

Study No.	Title of the Study	Objectives of the Study	Dependent and Independent Variables	Highway Used
F-1	A study for developing data based on sign reading behaviors of drivers.	to collect driver eye-movement data under different signing and traffic conditions to generate a data base. The data base was primarily intended for developing an understanding into sign reading behaviors of drivers, and subsequently it was used to develop a methodology for evaluating road signs.	Dependent Variables Sign evaluation measures (see page) Independent Variables 1. relevancy of signing to the driving task (3 levels) a. no relevancy b. relevant but not pertaining to route c. relevant and pertaining to route 2. type of mounting a. side mounted b. overhead mounted 3. visual loading (3 levels) a. open road driving b. car following c. car following at minimum safe distance 4. signing density a. low b. high	1. I-71 between Stringtown Road and SR 41 2. I-71 between Broad Street and I-270 (North Section) (Columbus)
F-2	A controlled validation study using speed limit signs.	1. to determine the maximum sight distances from which a sign could be read while driving 2. to determine relationship of sight distance to visual acuity of drivers 3. to determine the effect of lateral placement of signs on the sign reading behaviors of drivers	Dependent Variables 1. maximum sight distances at the initiation of driver control response 2. sign evaluation measures Independent Variables 1. speed prior to response to a speed limit sign (4 levels) 2. height of letters on speed limit signs (2 levels) 3. lateral position of sign (2 levels)	I-70 between SR 29 and SR 142 (before this section of I-70 was open for traffic)
F-3	An exploratory study for investigation at sign reading by extra-foveal vision.	to investigate the possibility of sign reading by extra-foveal vision while driving for the validation of assumption used in the developed methodology	Dependent Variables amount of message read by the driver Independent Variables location of fixation point (2 levels)	I-270 (southwest section)

Table 1.1 (con't)

F-4	A study for the evaluation of sign changes on I-90.	to apply the developed methodology for evaluating sign changes made by the Ohio Department of Highways on I-90 in Cleveland	Dependent Variables sign evaluation measures Independent Variables signing differences a. old signing b. new signing	I-90 in Cleveland between Liberty Blvd. and Babbitt Rd.
F-5	A study for determination of T_{reqd} using Programmable Research Sign	to determine minimum time necessary to acquire required information from a sign while driving	Dependent Variables T_{reqd} = minimum time (in seconds) required to acquire required information from the sign Independent Variables 1. length of message a. lines (2 levels) b. words (2 levels) 2. familiarity (2 levels) 3. type of information needed	SR 33 (one mile section east of Scottslawn Rd. entrance ramp
F-6	A study for the investigation of effects of sequential and multiple signs.	to investigate the effect of the following two variables on sign reading behavior of drivers: i. number of signs per location (multiple signs) ii. number of locations of sign (or signs) per exit (sequence of signs)	Dependent Variables sign evaluation measures Independent Variables 1. number of signs per location (3 levels) 2. number of sign locations per exit (3 levels)	I-270 and I-70
F-7	A study of signing in Akron.	to determine effects of signing providing information conflicting to highway geometrics on sign reading behavior of drivers	Dependent Variables sign evaluation measures Independent Variables geometric configurations i. right hand turns for continuing on highways on left hand side ii. left hand turns for continuing on highways on right hand side iii. left hand exit	I-80S, I-77 and I-277
F-8	A study of signs of special interest	to study sign reading behaviors of drivers under signing situations of the following type: i. generally regarded as "confusing" ii. special merging signs iii. diagrammatic signs	Dependent Variables sign evaluation measures Independent Variables signing situations	JCT of i. SR 33 and I-71 on west side of Columbus ii. I-270 and I-71 interchange on south side of Columbus, and iii. I-70 (west) at SR 79 (south) exit

Table 1.2

Summary of Laboratory Experiments

Study No.	Title of the Study	Objectives of the Study	Dependent and Independent Variables
L-1	A study for preliminary investigation of T_{reqd} by tachestoscopic presentations of signs.	to determine effects of length of message and familiarity on minimum time necessary to read standard highway signs	<u>Dependent Variable</u> = No. of tachestoscopic exposure of 0.01 sec. duration required to read message presented on the sign <u>Independent Variable</u> 1. length of message in number of lines (4 levels) 2. familiarity (3 levels)
L-2	A study for determination of T_{reqd} by using laboratory eye-movement recorder.	to determine if data on T_{reqd} obtained by using laboratory setup can be compared with data collected in a similar experiment (reference study no. F-5) conducted under actual driving situations	<u>Dependent Variable</u> = minimum time (in seconds) required to acquire required information from a sign <u>Independent Variable</u> 1. length of message a. lines (2 levels) b. words (2 levels) 2. familiarity (2 levels) 3. type of informational need (3 levels) 4. position of needed information on the sign (4 levels)
L-3	A study for relating T_{reqd} with amount of message acquired from signs.	to determine relationship between amount of time spent in reading signs and percentage of total message acquired	<u>Dependent Variable</u> No. of tachestoscopic exposures of 0.200 sec. duration. <u>Independent Variable</u> 1. length of message displayed on a sign (3levels)

The majority of driver eye movements in this research were collected under experimental conditions such that the subject drivers were totally unaware of the objective of this research. The drivers under field studies were only given freeway entering and exiting instructions and nothing was mentioned to them about the signing. The collection of driver eye-movement data, thus, enabled the researcher to obtain unbiased (instruction free) data on the sign reading behaviors of the drivers over a time. Field studies F-2 and F-5 (see Table 1.1) included testing under controlled situations where specially designed research signs were erected and employed with the cooperation of the Ohio Department of Highways.

The three laboratory studies in this research were conducted primarily to investigate the effect of message content and informational need of the driver on the minimum time necessary to acquire information from a sign.

Results

Chapter IV presents the description, data analysis, and results obtained from all the eleven studies conducted in this research.

Summary of Results

The analyses of the data obtained from the eleven studies conducted in this research has provided many interesting relationships between the sign reading behaviors of the drivers and many different factors related to the characteristics of the signing, of the drivers, the highways, and the traffic situations. The results when put together provided a unique opportunity in uncovering the mechanism involved in the understanding of the sign reading behaviors of drivers. The understanding into how various different factors influence the sign reading behaviors of the drivers provide a basis for the implementation of the methodology for both the evaluation and the design of highway signing.

The results, in general, indicate that the values of the majority of the evaluation measures and the relationships between different measures are significantly affected by the following factors.

1. Factors related to differences in signing characteristics:

   a. letter size,
   b. length of message,
   c. relevancy of message with respect to exiting or route following instructions,
   d. type of mounting,
   e. number of signs in a sequence of signs presenting the same route guidance information, and
   f. multiple signs(number of signs at a location).

2. Factors related to drivers (i.e., factors responsible for inter-subject and intra-subjects differences)

   a. characteristically different sign reading behaviors of individuals (e.g., some drivers were found to be habitually sampling excessively at the signs than others),
   b. binocular visual acuity of the driver's visual field,
   c. characteristics of driver's informational needs (i.e., type of information needed, urgency of the informational need), and
   d. driver familiarity with the highway.

3. Factors associated with visual load on the drivers:

   a. traffic density - car-following demands, and
   b. special driving instructions (e.g., in one of the studies the driver instructions were: "Stare at the lead car as much as possible and exit at Cleveland Avenue.").

4. Factors related to highway geometry (i.e., the relation of the characteristics of signing to the characteristics of the geometric design of the highway)

   a. signing at the most commonly designed highway geometric situations (e.g., standard right hand exit), and
   b. situations where signs present information contradictory to the geometric highway design (e.g., signing requiring a turn to the South in order to eventually end up going North).

Before presenting the results obtained in this study in detail, it seems important to acquaint the reader with the range of values of the measures considered for the study.

Five subjects were used for the data collection in this research. Their binocular foveal visual acuities ranged between 20/15 to 20/35. In general, the 50th percentile values of the measures T_{max}, T_f and T_e for standard freeway signs and traveling at about 60 mph, respectively, ranged between 11 to 16 seconds, 7 to 10 seconds, and 1 to 4 seconds.

Table 1.3 summarizes the results illustrating the effects of some important independent variables on the sign evaluation measures. It should be noted that the arrows in this table show the directions in which the sign evaluation measures were found to be related with increases in the value of each of the independent variables.

Table 1.3

Summary of Results Illustrating the Effect of Independent Variables on the Sign Evaluation Measures

Serial Number	Independent Variable / factor	The effect of an increase in the value of the independent variable on the sign evaluation measures					
		T_{used}	T_f	T_e	T_i	T_{max}/T_f	T_i/T_{used}
1	Traffic density (open road driving to car following)	↓ F-2	↓ F-1 F-6 F-7	UA	↓ F-1 F-6 F-7	↑ F-1 F-6 F-7	UA
2	Signing relevancy (i.e., relevnacy of sign to the driving task) (not relevant - pertaining to route)	↑ F-1 F-4	NAE	↓ F-1	↑ F-1	NAE	↓ F-1 F-4
3	Type of informational need	→ F-5 L-2	NC	NC	NC	NC	NC
4	Driver urgency associated with obtaining information from the sign	NC/NA	↑ F-4	NC/NA	NC/NA	↓ F-4	NC/NA
5	Driver familiarity with the highway (or signs)	↓ F-4 F-5 L-1 L-2	↓ F-4	↑ F-4	↓ F-4	↑ F-4	UA
6	Average angular location of the sign from the path of the vehicle	↓ F-4	↓ F-2 F-4	↑ F-4	↓ F-4	↑ F-4	NAE
7	Location of sign in the sequence of signs	F-1 → F-4 F-6	F-1 → F-4 F-6	F-1 → F-4 F-6	F-1 → F-4 F-6	F-1 → F-4 F-6	F-1 → F-4 F-6
8	Position of a sign in a group of (multiple) signs at a location	→ F-7	→ F-7	→ F-7	→ F-7	→ F-7	→ NAE
9	Awareness of a sign and its legibility (size of sign and size of letters)	NC	↑ F-4	NC	NC	↓ F-4	↑ F-4
10	Amount of message (i.e., words, lines and letters) on the sign and message complexity	↑ F-4 F-5 L-1 L-2 L-3	NA/NC	↓	↑	NA/NC	↓

Notation:

↑ Value of sign evaluation measure increases with increase in the value of independent variable

↓ Value of sign evaluation measure decreases with increase in the value of independent variable

→ Significant effect due to levels of independent variable (difficult to quantify)

UA = unaffected, NAE = no apparent effect, NC = not considered, NA = not applicable

Note: The numbers on the side of the arrows indicate the reference number of the studies in which the effects were observed.

In the following pages some of the important and more specific results are presented briefly.

1. It was found that the variable T_f (defined as the maximum time-distance from which a driver actually begins to acquire resolvable information from a sign) is the "key" variable for both the evaluation and design of road signs. This is primarily because how a driver acquires information from the sign was found to depend highly upon when he begins to attend to the sign. The period (T_f - T_{eblr}) denotes the time that is available to the driver to read the signs until he passes the sign. Therefore, depending upon the driver's informational need, the driver had to adapt his sign reading behavior in the period (T_f - T_{eblr}) to obtain required amounts of information from the sign.

2. The measures T_{max} and T_f were found to be significantly and positively correlated. (See Table 1.4.) The positive correlation between T_f and T_{max} suggests that T_f is related to the factors that are associated in determining T_{max}. The primary factors that are needed for the determination of T_{max} are as follows:

    a. maximum letter size(i.e., the highest size letter on the sign),

    b. visual acuity of the driver,

    c. velocity of the vehicle, and

    d. location of the sign with respect to the driving lane.

3. The ratio T_{max}/T_f was found to be a good descriptor of the sign utilization by the drivers; i.e., if T_{max}/T_f is equal to 1.0 this would mean that the driver can begin to acquire information from the sign as soon as it is legible. The higher the value of T_{max}/T_f is, the less is the utilization of the information availability of the sign.

    a. The ratio T_{max}/T_f was found to increase as the visual load on the driver's information acquisition process increased. It was found that the values of the ratio T_{max}/T_f under car-following situations were higher when compared to the values of the T_{max}/T_f for the same drivers under open road driving situations. (See Figure 1.5.)

Table 1.4

Summary of Correlation Between the Measures T_{max}, T_f, and T_{used}

Study Number	Abstract of Experimental Condition	T_{max} and T_f	T_f and T_{used}	T_{max} and T_{used}
F-1	open road driving	0.3291***	0.3077*	-0.0466
	normal car following	0.2973**	0.3780**	-0.1069
	car following at minimum safe distance	0.2412***	0.5334****	-0.16025
F-4	Signing on I-90 Old Signs New Signs	 0.552**** 0.642****	 0.186** 0.415***	 0.064 0.197***
F-6	car following under instructions to stare at the lead car	0.505***	0.684***	0.268
F-7	under conditions of difficult route selection in moderate to heavy traffic density	0.497* to 0.769*	0.416* to 0.902*	0.48* to 0.853*

Notation:
p = significance level
* = $p < 0.25$
** = $p < 0.10$
*** = $p < 0.05$
**** = $p < 0.01$

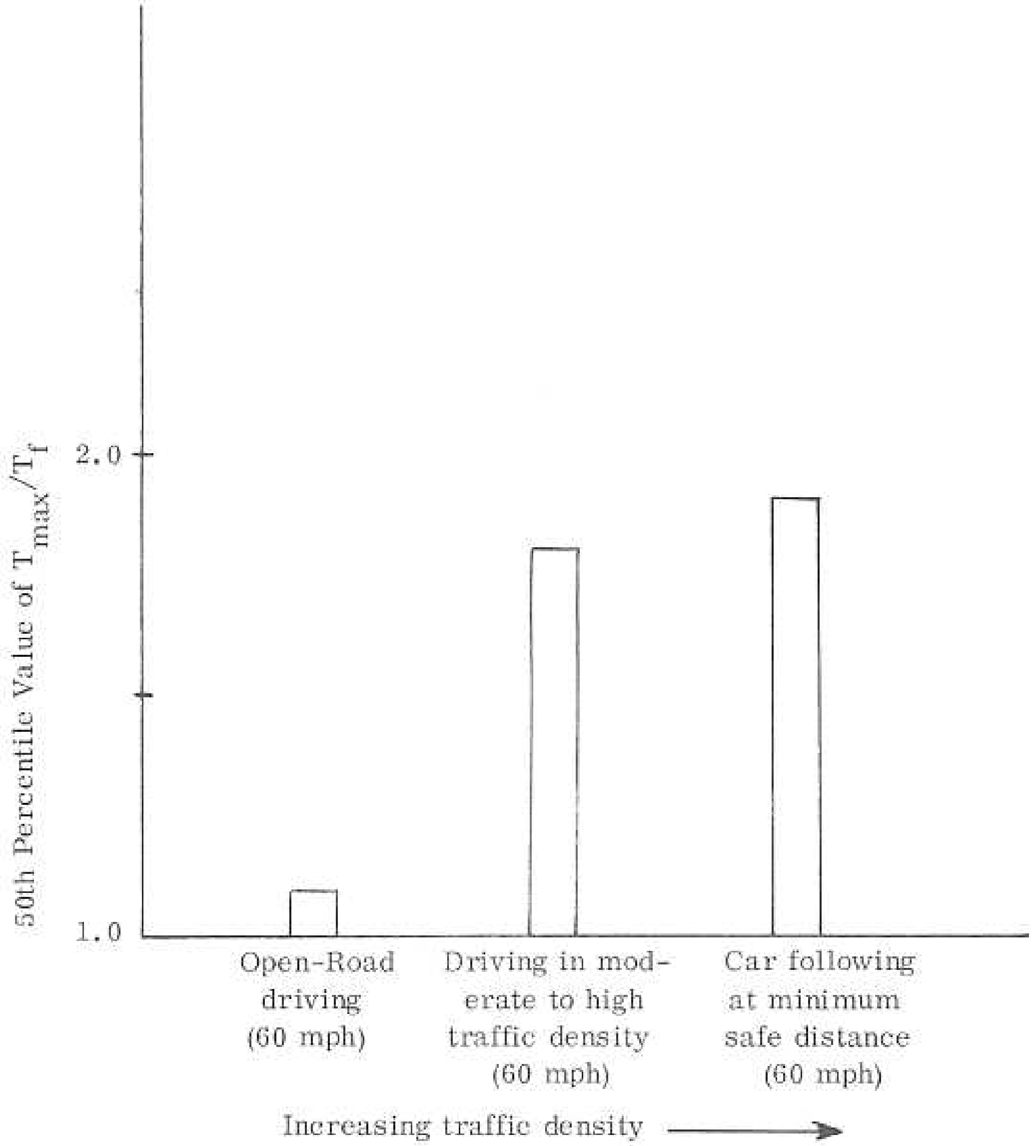


Figure 1.5.--Illustration of the Effect of Traffic Density on the Measure T_{max}/T_f

b. The ratio T_{max}/T_f was found to decrease with increase in driver urgency in obtaining information from the sign.

c. The values of T_{max}/T_f, in general, were higher for side-mounted signs as compared to the over-head mounted signs.

4. The manner in which T_{used} was found to be related to different factors is as follows.

   a. The measure T_{used} was found to be significantly and positively correlated to T_f, indicating that if T_f is higher, a driver can spend more time in obtaining information from the sign. (See Table 1.4.)

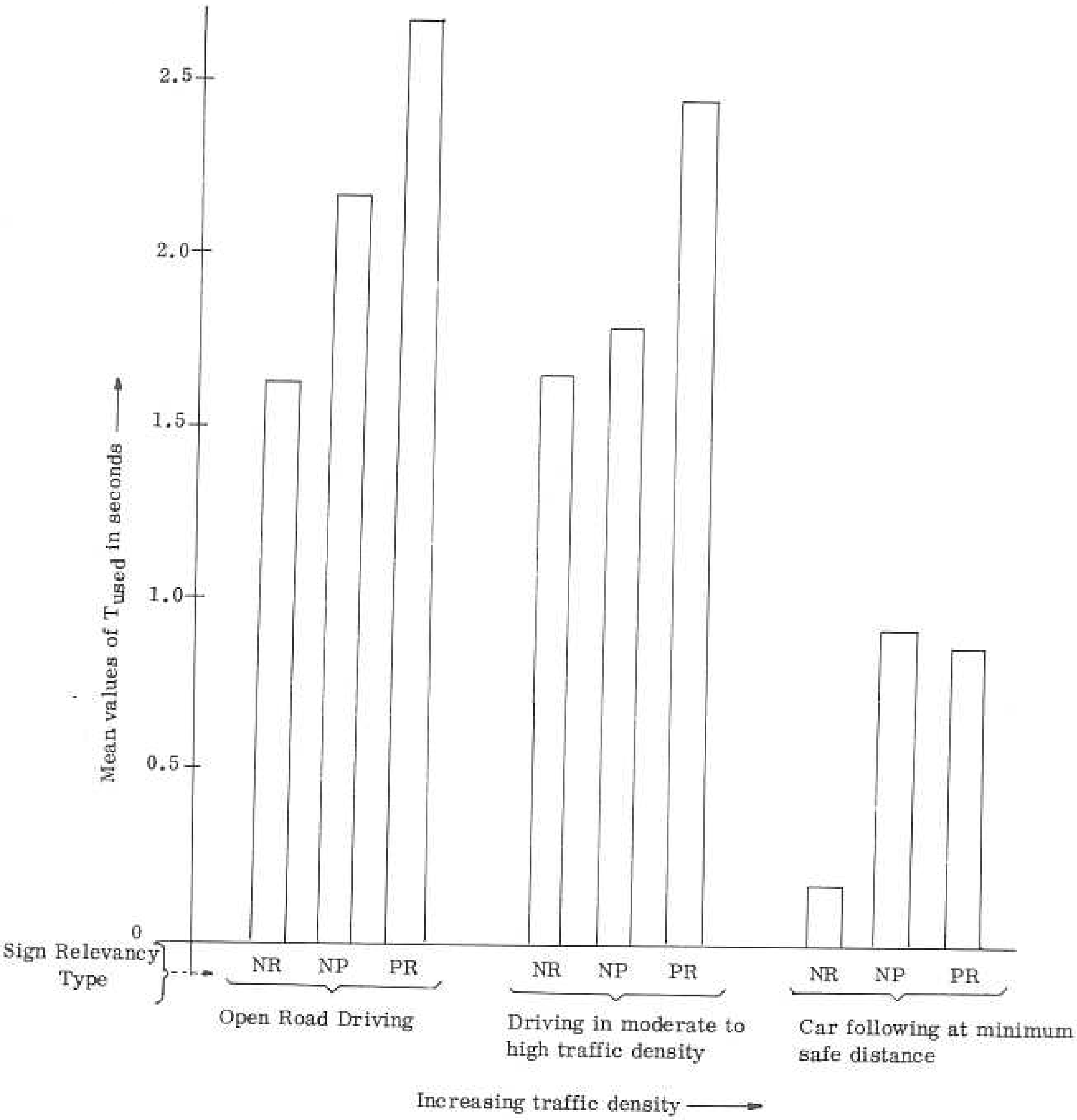
   b. Sign Relevancy: It was found that T_{used} increases with increase in relevancy of the information presented by the sign in relation to the driver's objectives. (See Figure 1.6.)

   c. The measure T_{used} was found to be related to visual load on the driver due to traffic situations. More specifically, it was found that as the traffic density increases, the time that is available for the drivers to obtain information from the signs decreases. (See Figure 1.6.)

   d. It was found that T_{used} depends upon the amount and type of information the driver needs. The measure T_{used} was found to increase with increase in length of message presented on the sign. Further, it was found that values of T_{used} were higher when the information required by the driver was displayed on the sign as compared to when the displayed information did not contain the information required by the driver.

   e. Effects of Sequential Signs: It was found that in a sequence of signs such as, (1) X Road, Exit 1 Mile, (2) X Road, Exit 1/2 Mile, (3) X Road, Exit Next Right, the values of T_{used} for the first sign are generally higher than the values of T_{used} on the subsequent signs, except for the last sign (or signs) where a major control action such as exiting or lane changing is required.

   f. Position of a sign in a group of (multiple) signs at a location: When a driver approaches a group of signs the values of T_{used} were found to be governed by the following factors:



Note:

NR = signs that are "Not Relevant"; i.e., the driver does not need information from the sign to continue on the highway

NP = Not Pertaining to route; i.e., the signs that do not present information pertaining to route or destination

PR = Pertaining to Route; i.e., the signs that present relevant information pertaining to route or destination

Figure 1.6.--Histograms Showing the Effect of Signing Relevancy and Traffic Density on T_{used} (from Study F-1)

i. natural tendencies of the drivers in relation to driver objectives and positional expectancy of relevant signs, and

ii. it was found that a driver wanting to continue on the highway (i.e., in "Thru Traffic") generally spends more time looking at the signs on the left hand side, whereas a driver wanting to exit generally spends more time on looking at signs on the right side.

g. Familiarity of the driver with the highway: It was found that as the driver gets familiar with a sign he requires less time to obtain information from the sign. It should be noted that T_{used} was found to be negatively correlated to driver familiarity, but if the signing is inadequate, poor or confusing at low levels of increasing familiarity, T_{used} was not found to increase with increase in familiarity. (See Figure 1.7.)

h. It was found that the drivers do not just concentrate on a sign (after T_f) until they obtain the required information from the sign, but they share their time after T_f between the sign and objects on the road. It appears that under normal freeway driving situations; i.e., under low to moderate visual loads, and for adequate signs the driver time-shares with the signs such that the 50th percentile values of T_i/T_{used} lie between 3.00 to 4.00.

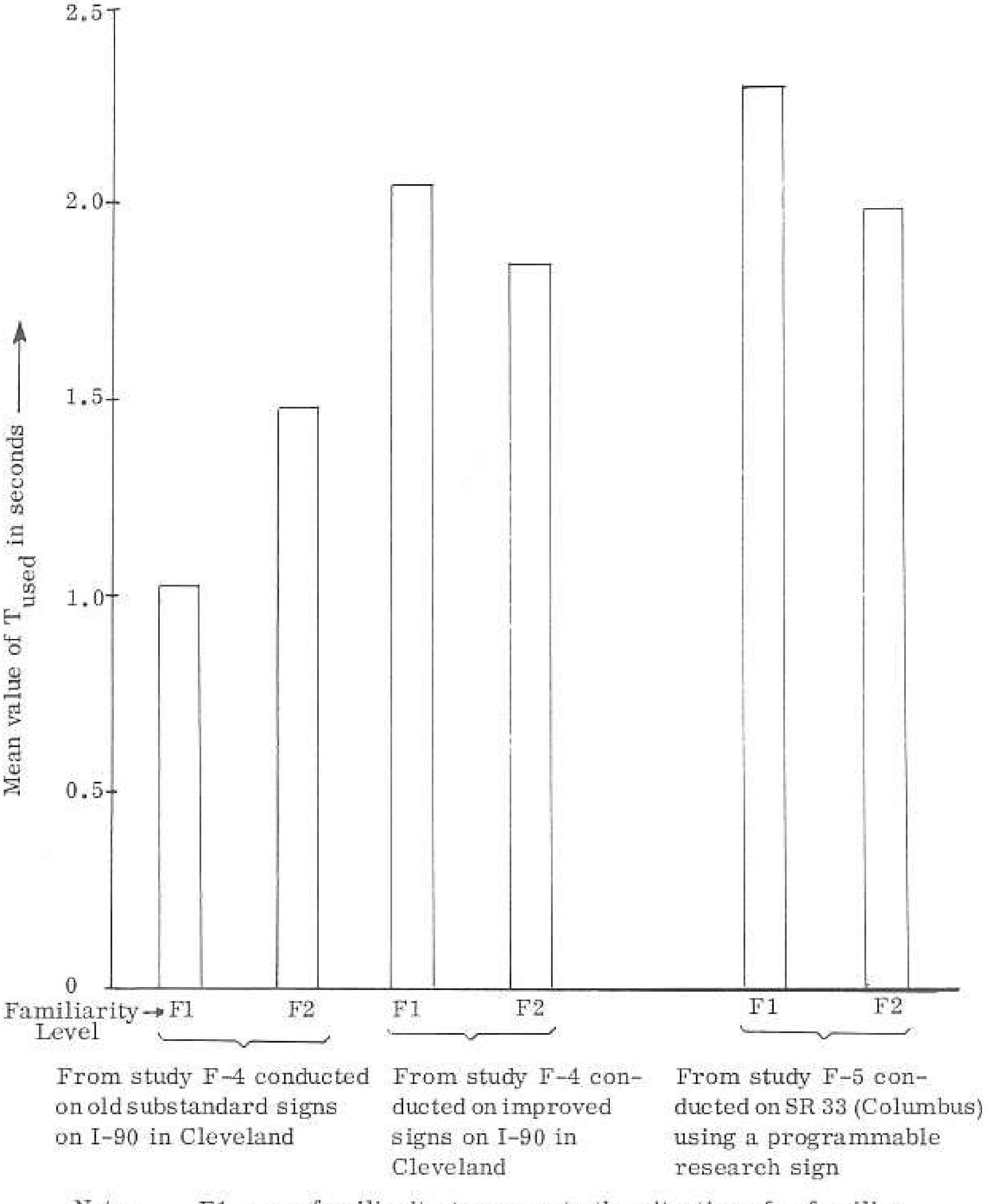
i. The drivers, in general, do not read all the information displayed by a sign but make trade-off decisions between amounts of information to be acquired from the sign and time to be spent in performing other driving tasks.

j. As the relevancy of signing with respect to the driver's informational need increases the values of T_i/T_{used} decrease.

k. The minimum time necessary to acquire required information from a sign was found to be related to different variables as follows:

i. T_{reqd} decreases with increase in driver familiarity.

ii. T_{reqd} increases with increase in the amount of message read by the driver. (See Figure 1.8.)



Note: F1 = no familiarity (represents the situation of unfamiliar driver)
F2 = low familiarity (represents the situation of an unfamiliar driver driving second time on the test route)

Figure 1.7.--Histograms Illustrating the Effect of Driver Familiarity on T_{used}

iii. When a driver is looking for a specific information; e.g., destination, such as how many miles is Eddy Road, the minimum time necessary to obtain such information depends upon the position of that information on the sign. It was observed that the drivers, in general, read the signs from top to bottom. Therefore, if the required information is displayed on the top line, T_{reqd} is the smallest.

iv. When the information needed by the driver is presented on the sign, the driver, in general, requires less time than if the required information is not presented on the sign. (See Figure 1.8.) Further, it was found that when a driver is searching for specific information on a sign, the minimum time necessary to search and acquire the information, in general, increases with increase in the amount; i.e., words and lines displayed on the sign. (See Figure 1.8.)

l. When the difference (T_{used} - T_{reqd}) is negative, it would indicate one of the following possibilities:

i. driver reading only a partial message from the displayed message on the sign, and

ii. familiar driver:

a. familiar to the highway, and

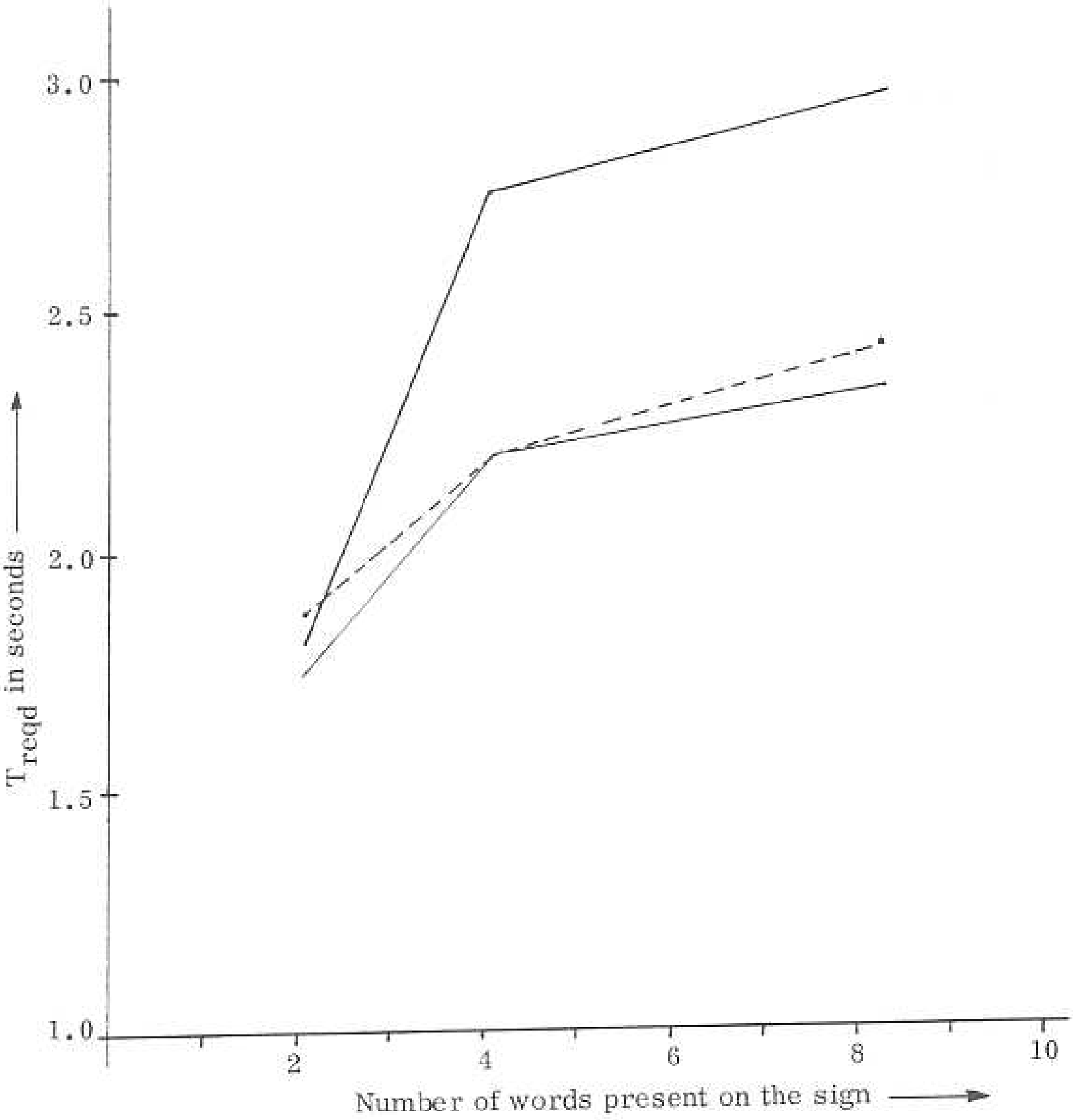
b. familiar due to more complete reading of the preceeding signs.

m. The sign reading behaviors of drivers driving on unfamiliar road under "confusing" (or contradictory signing) and "inadequate" signing situations had the following characteristics:

i. high values of T_{max}/T_f (over 2.0),

ii. low values of T_i/T_{used} (less than 2.5), and

iii. very low values of T_e; i.e., T_e approximately equal to T_{eblr}.



Notation: IN1 = searching for milage number for a given destination
IN2 = searching for a given destination when it was displayed along with other destinations
IN3 = searching for a given destination when it was not displayed on the sign

Figure 1.8.--Graph Illustrating the Effects of the Number of Words Displayed on the Sign and the Type of Information Need (IN) of the Drivers on T_{reqd}

Implementation of the Results

The results obtained in this research, in general, provide information in understanding how drivers obtain information from the signs under different driving and signing conditions. Therefore, as stated earlier, the problem of the evaluation of the signs can be effectively solved if a proper match between the sign reading behaviors of the drivers, the characteristics of the signing, and related variables such as traffic density, highway geometry, etc., is achieved.

When all the results obtained in this research are assembled, they suggest that the most important variables associated in determining the degree of match between a sign and the sign reading behaviors of the drivers are as follows:

1. T_f (defined as the maximum time distance from which the driver first begins to acquire information from an approaching sign),

2. T_{eblr} (defined as the minimum time distance from which a driver can obtain information from the sign),

3. T_{reqd} (defined as the minimum time necessary for the driver to obtain the required information from the sign), and

4. T_{used} (defined as the time during which a driver obtains or can obtain information from a sign).

The above four variables, when further analyzed in relation to the following variables, provide detailed information on how a driver shares or utilizes the time period $(T_f - T_{eblr})$:

1. the difference between T_{used} and T_{reqd},

2. T_i/T_{used},

3. $(T_f - T_{eblr})/T_{reqd}$, and

4. the relationship between T_f and T_{max}, when considered by the ratio T_{max}/T_f, provides information about the driver urgency and utilization of the sign information availability.

The characteristics of good signs can therefore be briefly presented as follows. The value of T_{max} should be sufficiently high such that for an unfamiliar driver:

1. the ratio T_{used}/T_{reqd} should be close to 1.0 (note: under higher visual loads),

2. the ratio T_i/T_{used} should be large; i.e., at least approximately over 3.0, and

3. the ratio T_{max}/T_f should be close to 1.0.

It should be noted that as T_{max}/T_f increases it indicates decreased utilization of the availability of the visual information displayed by the sign. Further, smaller values of T_i/T_{used} show increased concentration of the driver on the sign in his time-sharing process with the sign and other driving tasks. For an unfamiliar driver, if the ratio T_{used}/T_{reqd} is smaller than 1.0, it would indicate partial reading.

Since there exist inter-subjects and intra-subject differences in the sign reading behaviors of the drivers, it is extremely difficult to make inferences about the adequacy of a sign just by observing data of one subject. Therefore, it is recommended that the data on sign reading behavior of many subjects for the sign to be evaluated must be collected, and based on the characteristics of the distributions of the above developed measures, inferences on the "goodness" or "adequacy" of a sign should be drawn.

From the distribution functions of the sign reading behavior of a driver the following estimates can be obtained in relation to certain preestablished criteria values such as K_0^*, K_1^*, . . . , K_4^*.

1. Evaluation of information availability:
   Estimate of the probability that $T_{max} \geqq K_0^*$

2. Evaluation of sign utilization and driver urgency:
   Estimate of the probability that $T_{max}/T_f \leqq K_1^*$

3. Evaluation of the completeness of
   Estimate of the probability that $T_{used} \geqq K_2^*$
   (Note: K_2^* can be selected as a suitable percentile value of the T_{reqd} obtained from the distributions of T_{reqd}.)

4. Evaluation of the time-sharing process:
   Estimate of the probability that $T_i/T_{used} \geqq K_4^*$

5. Estimate of $K_3^* - K_4^*$ where K_3^* is the theoritically computed value on the estimate of the time-sharing process as follows:
   $K_3^* = (T_f - T_{eblr})/T_{reqd}$.

In general, it can be stated that the higher values of the above described probability estimates would indicate better effectiveness of the sign.

It should be noted that in this research the data on the sign reading behavior of drivers under many different driving situations was obtained to gain an understanding into how the values of the sign evaluation ratio are related to different variables involved in the problem of the evaluation of the signs. From such an understanding the critical values of the variables K_0*, K_1* . . . , K_4* would be selected for both the evaluation and design of a road sign for matching the characteristics of the sign with the sign reading behavior of the drivers under the traffic and highway situations existent on the vicinity of the sign.

Current highway signing standards presented in the Manual of Uniform Traffic Control Devices for Streets and Highways do not provide sufficient information to a highway engineer for designing highway signs.

The sign design guidelines presented in such manuals provide information to a highway engineer that only makes him aware of the considerations such as:

1. use of safety factors to account for driver inattention, and

2. time associated in reading the sign, etc.

The findings of this research when further investigated and implemented would provide quantified information on many such considerations that are currently merely described as guidelines without mathematical explicitness in the Manual of Uniform Traffic Control Devices.

For example, some of the findings of this research offer solutions in the following directions in designing signs by considering sign reading behaviors of the drivers.

1. This research has shown that the 50th percentile values of T_{max}/T_f, under normal traffic conditions and lower visual loads lie in the neighborhood of 1.5; whereas, under higher visual loads (due to higher traffic density) the 50th percentile values of T_{max}/T_f tend to lie over 2.0.

   This result clearly indicates that if the signs have to be designed by considering the driver's sign reading behaviors, a highway engineer should not merely consider the legibility distances but should take into account the factor T_{max}/T_f (obtained for the level of traffic density on the highway where the sign would be installed).

2. This research has shown that the time required by the driver to obtain information from the sign is dependent upon the factors such as:

a. length of message displayed on the sign, and

b. type of informational need of the driver, etc.

Therefore, based on this research and future research in this area, some estimates of T_{reqd} and T_{used} can be provided to a highway engineer for better design of the signs.

3. Further, in this research it was found that the drivers do not just concentrate on the sign to obtain information, but they time share with the sign. Therefore, standard values of T_i/T_{used} for different driving and signing conditions can be established for better design of the signs.

The above discussions were presented only for the purposes of illustration. It appears that a more complete and detailed implementation of this research would lead towards developing schemes and guidelines for both the evaluation and design of road signs.

A research contract entitled, "Implementing Sign Research Results Into Operational Practices," (Project EES 407B) was awarded to the Systems Research Group to continue research work in this area. The specific objective of the research work in Project EES 407B is to implement the results obtained in this research study along with other findings available in the areas related to the problem to develop an operational tool that can be used by a highway engineer to solve the signing system design and evaluation problems. The research work proposed in the Project EES 407B is being aimed at developing a computer model which will, (a) take into account all the necessary design and operational factors (such as highway geometry, traffic flows in each of the lanes, the range of sign reading behavior and visual capabilities of drivers, etc.) and their relationships and (b) perform calculations to provide (1) detailed signing system design, (2) measures describing "goodness" or "effectiveness" of the design and (3) determine costs that will be incurred in building, installing and subsequent maintenance of signs if a signing system designed (or existing designs improved) under such specifications is actually put into practice.

The above described computer model will have two basic sub-models:

1. to implement the research results for evaluating road signs, and

2. to implement the research results for design of new signs.

Figures 1.9 and 1.10 briefly describe examples of possible schemes in which the results obtained from this research study can be implemented to solve the problem of evaluation and the design schemes would show some criterion values (such as, K_0*, K_1*, K_2*, . . . etc.) which will be established by reanalysis of the data obtained from this study.

For example, for the evaluation of a road sign (see Figure 1.9) the estimates of the following measures will be considered:

1. probability that $T_{max} \geq K_0^*$,
2. probability that $T_{max}/T_f \leq K_1^*$,
3. probability that $T_i/T_{used} \geq K_4^*$,
4. probability that $T_{used} \geq K_2^*$, and
5. $K_3^* - K_4^*$.

It should be noted that, in general, the higher the values of the above five measures the better the sign. Of course, the relative importance of each of the above five measures and selection of the criterial values will have to be considered in detail.

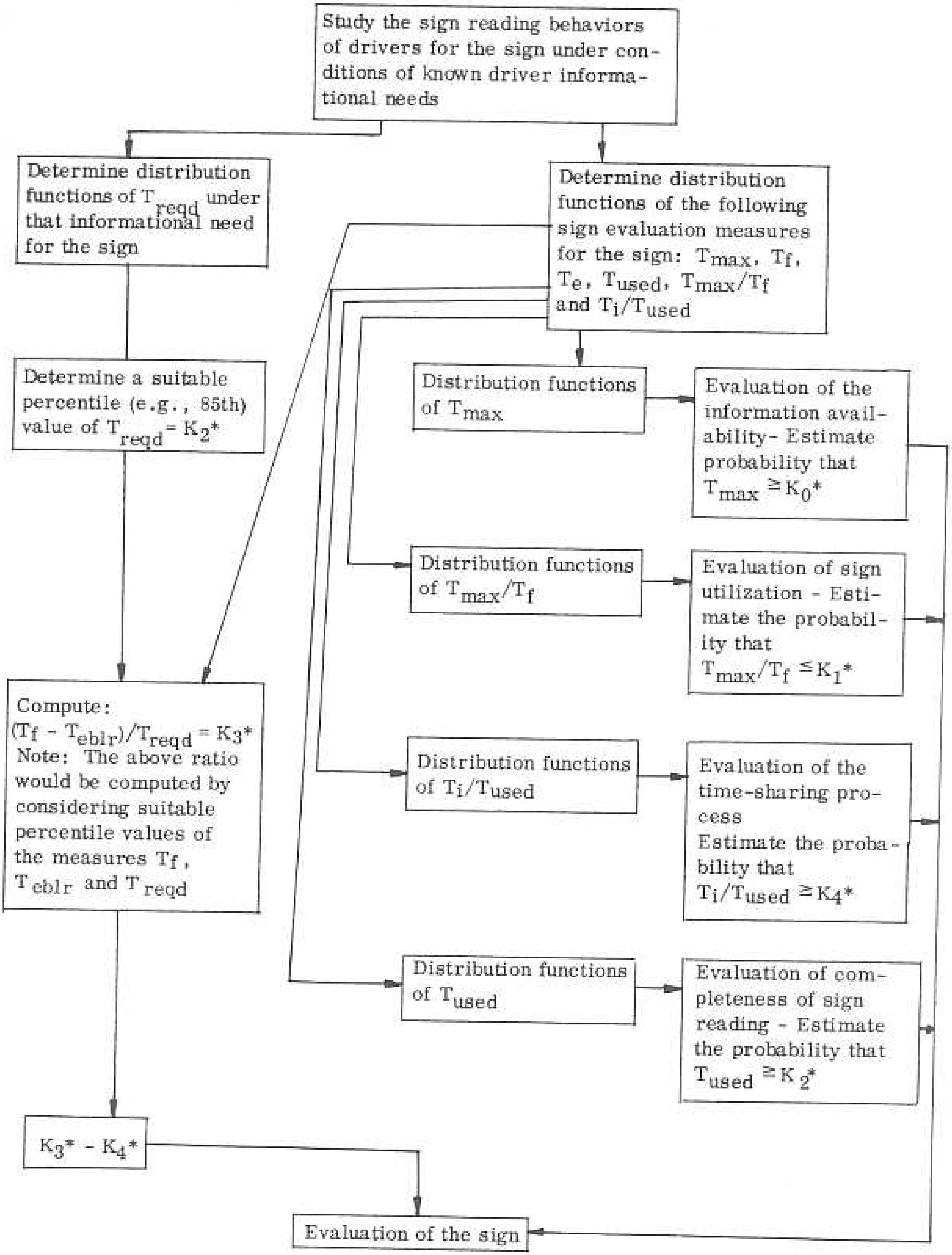


Figure 1.9.--Flow Diagram Showing a Scheme for the Evaluation of a Road Sign

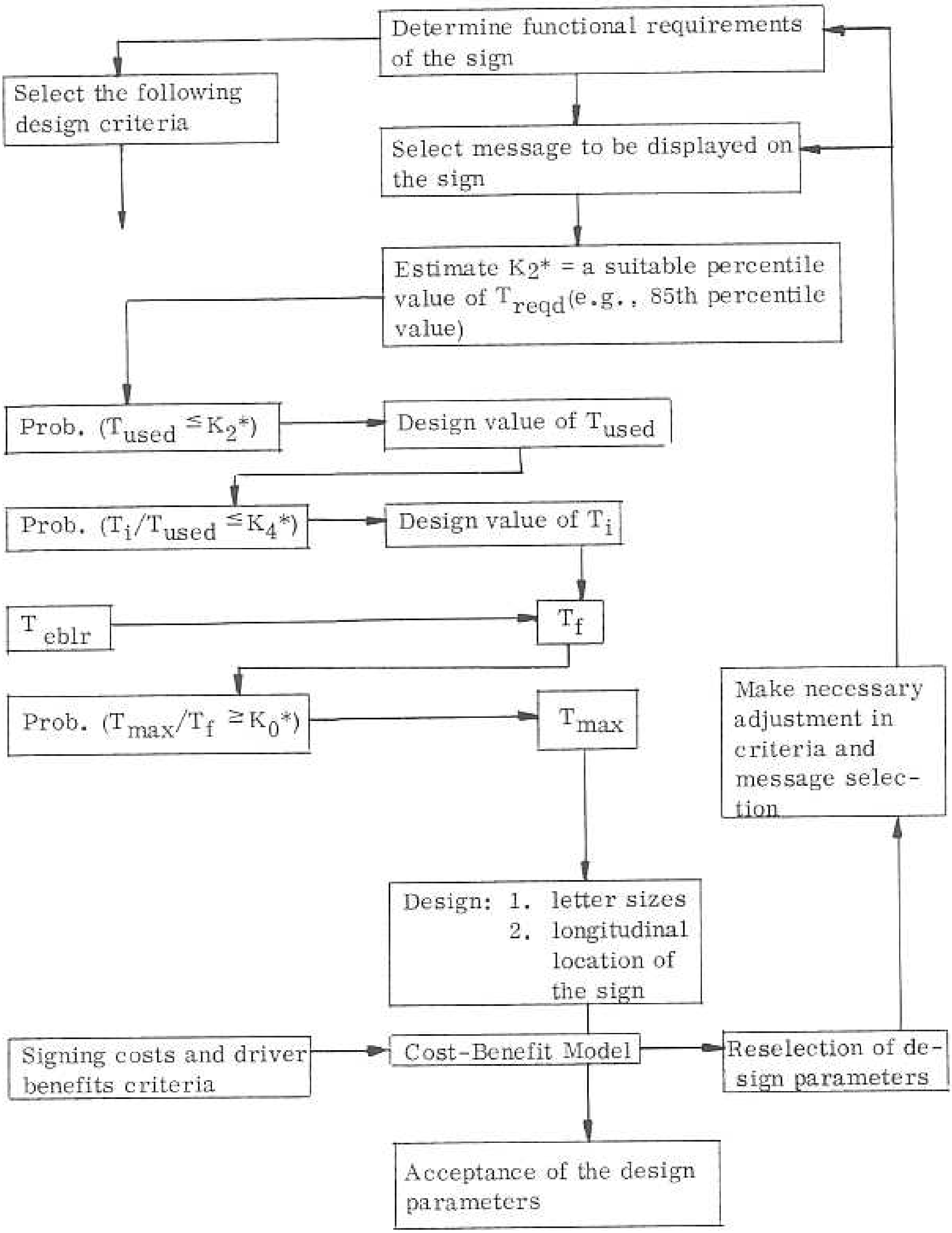


Figure 1.10.--Flow Diagram Showing a Scheme for the Design of a Road Sign