TOWARD THE DEVELOPMENT OF A METHODOLOGY FOR EVALUATING HIGHWAY SIGNS BASED ON DRIVER INFORMATION ACQUISITION

Vivek D. Bhise and T. H. Rockwell, Ohio State University

This paper presents the findings of a research study conducted to develop a methodology for evaluating road signs by the use of an eye-marker camera as a primary research tool. The methodology attempts to evaluate a road sign by determining the degree of match between the sign-reading behavior of drivers and the characteristics of the signs, the highway, and the traffic situations. Data were collected on the eye movements of drivers under actual driving situations involving more than 400 different Interstate highway signs. The data were analyzed by specially developed computer programs that also computed sign evaluation measures describing sign-reading behavior of the drivers. Further analyses showed that the sign evaluation measures were related to many factors associated with the characteristics of the signing, the driver, the highways, and the traffic situations. Understanding how various factors influence sign-reading behavior provides a basis for the implementation of the methodology for both the evaluation and the design of highway signing.

•THE PROBLEM of evaluating signs by determining the degree of "match" among the characteristics of the signs, the abilities of the drivers, and the other components of the highway such as the traffic and road geometrics was the focus of this research. The evaluation of the road signs was accomplished by using an eye-marker camera.

The eye-marker camera system provides continuous records of the driver's eye movements (i.e., where the driver's eyes are directed while driving) superimposed on the driver's view of the forward road scene, which includes important information such as traffic flows, sign configuration, and layout as the vehicle proceeds down the highway. The analyses of the eye-movement data recorded on film (or video tapes) enables a researcher to determine how a driver acquires, or does not acquire, information from oncoming road signs.

The use of an eye-marker camera system as a primary research tool for the evaluation of highway signs results in benefits not realizable with other types of measurement systems. One of those benefits is lack of bias. Eye movements are, to a large extent, involuntary and thus relatively bias free when compared with other types of driving performance parameters. Another benefit is lack of prejudice due to instructions. The reliance on information acquisition and control performance measures enables data concerning signing to be obtained without instructional references to the signing interest. For example, the instructions "Drive in your normal manner and exit at US-62" require that the driver rely on route guidance and regulatory signing without being specifically told about any of the signs that are being studied.

Further, an extensive review of signing-research literature conducted in the early stages of this research suggested that most signing research was conducted in the following 3 areas:

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1. Sign legibility (i.e., determination of effects of factors such as contrast of letters, height of letters, and stroke width on legibility distances),
2. Sign visibility (i.e., determination of effects of factors such as area of sign, color, and brightness contrast with background on "target value" or "attention value" of a sign), and
3. Driver's reactions to highway signing (which includes studies conducted by collecting data through traffic observations, e.g., erratic driver maneuvers, or driver interviews).

The literature in the areas mentioned above does not clearly address the basic question, How do drivers acquire or fail to acquire information from a sign? Clearly, because the information displayed by the sign is acquired visually by the drivers, the collection of eye-movement data to investigate sign-reading behavior of drivers is important. Both the consideration of the driver's visual capabilities (e.g., visual acuity) and the consideration of the driver's sign-information-processing capabilities and sign-reading behavior play a crucial role in the proper evaluation of highway signing.

OVERVIEW OF RESEARCH

The primary aim of the signing research involving eye-movement recordings was to develop an assessment technique for the evaluation of highway signs. The objectives of the research were, therefore, as follows:

1. To develop a scheme for measuring sign-reading behavior of drivers based on their eye movements;
2. To identify important variables related to the characteristics of the various components, such as drivers, signs, highways, and traffic, that affect the sign-reading behavior of the drivers;
3. To investigate the effect of those important variables on the sign-reading behavior of drivers;
4. To develop a methodology for evaluating road signs on the basis of the observed relations between sign-reading behavior and characteristics of signs, highways, and traffic; and
5. To use the developed methodology to evaluate various signing situations.

The experimental work in this 3-year research study included a set of 8 field studies and 3 laboratory experiments. In the field studies, the eye movements of test drivers were recorded under actual driving conditions for more than 400 Interstate highway signs. The 3 laboratory studies were conducted to relate sign reading under controlled laboratory conditions to the same signs studied under actual road conditions.

The objectives and experimental procedures of the studies are presented briefly in a later section of this paper. The objectives of each of the 11 studies were such that they collectively provided information for determining effects of the following variables on the sign-reading behavior of drivers:

1. Factors related to differences in signing characteristics, including (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 or number of signs at a location;
2. Factors related to drivers, including (a) binocular visual acuity of the driver's visual field, (b) characteristics of driver's informational needs (i.e., type of information needed and urgency of the informational need), and (c) driver's familiarity with the highway;
3. Factors associated with visual load on the drivers, including (a) traffic density (car-following demands) and (b) special driving instructions (e.g., in one of the studies, the driver's 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), including

(a) signing at the most commonly designed highway geometric situations (e.g., standard right 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 go north).

MEASUREMENT OF SIGN-READING BEHAVIOR FROM EYE MOVEMENTS

The sign-reading behavior of the driver can be defined as the visual behavior that is responsible for acquiring the information displayed by the sign. The driver's eye movements while he approaches a sign are only one of the variables that are needed in understanding how a driver acquires the information from the sign. More specifically, to evaluate whether a driver can or actually does acquire the information involves consideration of the following factors:

1. Characteristics of the sign (e.g., sizes of letters, contrast of letters with sign background, and size of sign),
2. Characteristics of the driver (e.g., his visual capabilities, eye movements, attention, and information processing loads),
3. Characteristics of visual information transmitting medium (e.g., visibility under different weather conditions),
4. Driver's location and path of motion on the highway with respect to the sign, and
5. Vehicle speed.

Further, while he is driving, the driver's eyes do not continually sample information but make successive discrete "fixations." A fixation can be defined as an apparent stationary position of the eyes between 2 successive eye movements. A driver can extract information from the optical image on his retinas only in a fixation (6). The durations of fixations while one is driving generally range between 100 to 600 msec.

The problem of measuring sign-reading behavior is, therefore, the same as the problem of measuring 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. One of the primary reasons for that complexity was found during the course of this research. The driver need not make direct fixation on a sign (i.e., directly point his eyes or visual axis on the sign) but can obtain information from the sign from extra-foveal parts of his 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 (1).

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

A detailed discussion of the considerations involved in making the above assumption and the definition of visual acuity are given by Rockwell et al. (5), LeGrand (4), and Davson (3). The above assumption was supported by conducting controlled field studies in this research (1). All field studies were conducted under daytime luminance levels ranging between 10 to 10^4 cd/m^2.

A computer program was developed to determine the availability (or resolvability) of information displayed by a sign to a driver in the successive eye fixations he makes as he approaches a sign. The program, which is called SEADEM (sign evaluation by analysis of driver eye movements), requires the following inputs:

1. Eye-movement data collected on the test section (eye-movement data consist 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;
4. Sign characteristics, such as location of sign, sizes of letters, sign size, and contrast; and
5. Visual acuity in the binocular visual field of the test driver.

With those inputs, SEADEM determines the 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 (Fig. 1):

T_{max} = maximum time-distance during which information displayed by the largest letter or symbol on the sign can form a resolvable image on the 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;
T_t = $(T_f - T_e)$ = 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); and
T_{emin} = minimum possible value of T_e below which a sign cannot present resolvable information to a driver because of limitation of driver's visual capabilities, angular position of the sign, and angular velocity of the sign in the driver's visual field.

In addition to the above measures, another measure called T_{min} was defined as the minimum time necessary for an unfamiliar driver to acquire information displayed by a sign.

For purposes of determining values and distributions of T_{min} as a function of variables such as length of displayed message and type of informational need of the driver in relation to the message displayed by the sign, a controlled experiment using a research sign that can be programmed was conducted. The description of the experiment is given in another report (1). The measure T_{min} was defined primarily to enable comparison between the observed values of T_{used} and T_{min} for the same sign and to investigate the problems related to partial or excessive sign reading by the drivers.

HYPOTHESIZED RELATIONS

The variables defined above were conceptualized (either by definition or for experimental testing) to be functionally related to various factors such as sign characteristics, driver familiarity with the route, and traffic density. A partial list of functional relations is briefly presented as follows:

T_{max} = f (size of letters, speed of vehicle, visual acuity, and location of driver with respect to sign);
T_{used} = g (traffic characteristics, familiarity, complexity of message on the sign, and highway geometry);
T_f = h (sign detection, urgency of information, traffic characteristics, visual acuity, and height of largest letter);
T_e = k (complexity of message, familiarity, T_f, height of the largest letter, and relevancy of message);
T_{emin} = l (relative angular position of sign with respect to driver's path, velocity, and visual acuity); and
T_{min} = m (complexity of message, familiarity, and relevancy of message).

In this research, the relevancy of the message displayed on the sign to the driver was defined by considering the following 3 categories:

1. Signs that are not relevant (NR), i.e., the driver does not need information to continue on the highway;
2. Signs that are not pertaining (NP) to route, i.e., that do not present information pertaining to route or destination; and
3. Signs that are pertaining to route (PR), i.e., that present relevant information pertaining to route or destination.

The following important basic hypotheses are some that were developed to investigate the functional relations presented above:

1. The time-distance at the first fixation from which the driver begins to sample information from a sign would be related to T_{max}. More specifically, it is hypothesized that, the higher the value of T_{max} is, the higher the value of T_f will be.
2. The measure T_f depends on the driver's informational need and on the visual load on the driver's information acquisition and processing capacity due to other driving tasks. It was hypothesized that, with an increase in the urgency of the information to the driver, the value of T_{max}/T_f would tend to move close to 1.0. Further, it is hypothesized that, with an 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 obtains information from a sign depends on (a) $(T_f - T_{emin})$ = total time available to the driver to obtain information from the sign, (b) relevancy of information presented by the sign in relation to driver's information need, (c) amount of message presented on the sign, and (d) visual information demands in performing other tasks in driving. The difference $(T_f - T_{emin})$ defines the maximum time that is actually available for a driver. It is, therefore, hypothesized that, depending on the information need, the driver time-shares his visual attention (in the period $T_f - T_{emin}$) between the sign and other sources that provide him information necessary to perform other driving tasks. The time-sharing process is further hypothesized to be a trade-off type of process where the driver has to make decisions on (a) proportion of $(T_f - T_{emin})$ 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) urgency associated with obtaining the information from a sign.
4. The ratio T_i/T_{used} is hypothesized to be a descriptor of the trade-off process mentioned above. The signs for which values of T_{used} are higher and the values of T_i/T_{used} are lower would then indicate the driver's increased concentration on the signs. Therefore, it is hypothesized that the important criteria for determining "adequacy" of a sign are (a) T_{max}/T_f should be as small as possible [the time period $(T_{max} - T_f)$ indicates unused time, i.e., a driver does not use the available information from the sign], and (b) values of the ratio $[(T_f - T_{emin})/T_{min}]$ should be greater than or equal to T_i/T_{used} (T_{min} is defined as the time required by an unfamiliar driver to obtain the needed information with no interpretation errors and, if less than T_{used}, indicates that the driver did not obtain all the information adequately or only partially read the sign).

SOME DETAILS CONCERNING THE FIELD DATA COLLECTION

The hypotheses presented in the previous section were investigated and the effects of many other factors on the sign-reading behavior of drivers were determined in 8 field studies. Table 1 gives some details concerning the studies. Details concerning each of the studies are given in the final report of this project (1).

In all 8 studies, the data were collected by using an instrumented vehicle that was equipped to record simultaneous synchronized data on eye movements and driving performance. The eye-marker camera system used in this research works on the principle of corneal reflection. The system essentially records superimposed images of the position of the driver's visual axis and the driver's forward visual scene encompassing a 20 x 20-deg visual field. A detailed description of the eye-marker camera system, the instrumented vehicle, and the data collection procedure used in this research is given in another report (1).

Most of the eye-movement data in this research were collected under experimental conditions, and the subject drivers were totally unaware of the objective of the research. In the field studies, drivers were only given freeway entering and exiting instructions, and nothing was mentioned to them about the signing. The collection of eye-movement data, thus, enables the researcher to obtain unbiased (instruction-free) data on the sign-reading behavior of drivers during a period of time. Field studies F-2 and F-5 (Table 1) included testing under controlled situations where specially designed research signs were erected and employed with the cooperation of the Ohio Department of Highways. In all the field studies, the total eye-movement data collected in this study amounted to more than 2,000 sign passages. The data were analyzed by the SEADEM computer program, and sign evaluation measures were computed.

The 3 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. The laboratory studies are described in the earlier report (1).

RESULTS

Many results were obtained from the 11 studies. In this section, basic findings are presented first and then some specific results are illustrated. Further, it is important for the reader to know the range of values of the different measures that were obtained in the studies.

Five subjects were used in this research. Their binocular foveal visual acuities ranged between 20/15 and 20/35. In general, the 50th percentile values of the measures T_{max}, T_f, and T_n for standard freeway signs and travel speeds of about 60 mph ranged from 11 to 16, 7 to 10, and 1 to 4 sec respectively. The values of T_{used}, in general, ranged between 0.5 and 4 sec.

The sign-reading behavior of a driver is a highly adaptive process. While the driver adapts his sign-reading behavior depending on relative level and importance of factors such as traffic density, relevancy of the sign with respect to the driver's intended destination, and driver's familiarity with the highways, there are some basic and relatively stable relations between T_{max}, T_f, and T_{used}. The word "stable" is used here to indicate that the relations do not appear to be appreciably affected by factors such as those described above. The basic and stable relations found among T_{max}, T_f, and T_{used} are as follows (Table 2):

1. T_{max} and T_f were found to be significantly and positively correlated under all types of driving and signing conditions;
2. T_f and T_{used}, in general, were found to be significantly and positively correlated under all types of driving and signing conditions; and
3. T_{max} and T_{used}, in general, were found to be uncorrelated.

The variable T_f (defined as the first time-distance from which a driver actually begins to sample information from a sign) is the key variable for both the evaluation and the design of road signs. That is primarily because how a driver acquires information from the sign depends highly on when he begins to attend to the sign. The period (T_f - T_{emin}) denotes the time that is available to the driver to read the sign before he passes it. Therefore, the results indicate that, depending on his informational need, the driver adapts his sign-reading behavior in the period (T_f - T_{emin}) to obtain required amounts of information during time T_{used} from the sign. Some positive correlation between T_{max} and T_f is expected because of the manner in which they are derived. T_f is dependent on eye movements, but T_{max} is independent of eye movements. The primary factors that are needed for the determination of T_{max} are maximum letter size (i.e., the highest size letter on the sign), visual acuity of the driver, velocity of the vehicle, and location of the sign with respect to the driving lane. It appears, therefore, that the positive correlation of T_{max} and T_f suggests that, as a driver approaches a sign, the

Table 1. Summary of field studies.

Number	Title	Objectives	Dependent Variables	Independent Variables
F-1	A study for developing data based on sign-reading behavior of drivers	To collect driver eye-movement data under different signing and traffic conditions to generate a data base, primarily intended for use in developing an understanding of sign-reading behavior of drivers and subsequently in developing a methodology for evaluating road signs	Sign evaluation measures	Relevancy of signing to the driving task (3 levels), i. e., no relevancy, relevant but not pertaining to route, and relevant and pertaining to route Type of mounting, side and overhead mounted Visual loading level, i. e., open-road driving, car following, and car following at minimum safe distance Signing density, low and high
F-2	A controlled validation study using speed-limit signs	To determine maximum sight distances from which a driver can read a sign To determine relation of sight distance to visual acuity of drivers To determine effect of lateral placement of signs on sign-reading behavior of drivers	Maximum sight distances at the initiation of driver control response Sign evaluation measures	Speed prior to response to speed-limit sign (4 levels) Height of letters on speed-limit signs (2 levels) Lateral position of sign (2 levels)
F-3	An exploratory study for investigation of sign reading by extra-foveal vision	To investigate possibility of a driver's sign reading by extra-foveal vision for the validation of assumption used in the developed methodology	Amount of message read by the driver	Location of fixation point (2 levels)
F-4	A study for the evaluation of sign changes on I-90	To apply the developed methodology for evaluating sign changes made by Ohio Department of Highways on I-90 in Cleveland	Sign evaluation measures	Signing differences, old and new signing
F-5	A study for determination of T_{reqd} using research sign that can be programmed	To determine minimum time necessary for a driver to acquire required information from a sign	T_{reqd} = minimum time (sec) required to acquire required information from sign	Length of message, lines (2 levels) and words (2 levels) Familiarity (2 levels) Type of information needed
F-6	A study for the investigation of effects of sequential and multiple signs	To investigate the effect on sign-reading behavior of drivers of number of signs per location (multiple signs) and number of locations of sign (or signs) per exit (sequence of signs)	Sign evaluation measures	Number of signs per location (3 levels) Number of sign locations per exit (3 levels)
F-7	A study of signing in Akron	To determine effects on sign-reading behavior of drivers of signs that provide information conflicting to highway geometrics	Sign evaluation measures	Geometric configurations, i. e., right turns for continuing on highways on left side, left turns for continuing on highways on right side, and left exit
F-8	A study of signs of special interest	To study sign-reading behavior of drivers under signing situations that are generally regarded as confusing, have special merging signs, and have diagrammatic signs	Sign evaluation measures	Signing situations

Table 2. Correlations of T_{max}, T_f, and T_{used}.

		T_{max} and T_f		T_f and T_{used}		T_{max} and T_{used}	
Number	Condition	Correlation	Significance Level	Correlation	Significance Level	Correlation	Significance Level
F-1	Open-road driving	0.3291	< 0.05	0.3077	< 0.25	-0.0466	
	Normal car following	0.2973	< 0.10	0.3780	< 0.10	-0.1069	
	Car following at minimum safe distance	0.2412	< 0.05	0.5334	< 0.01	-0.16025	
F-4	Old signs on I-90	0.552	< 0.01	0.186	< 0.10	0.064	
	New signs on I-90	0.642	< 0.01	0.415	< 0.05	0.197	< 0.05
F-6	Car following under instructions to stare at the lead car	0.505	< 0.05	0.684	< 0.05	0.268	
F-7	Difficult route selection in moderate to heavy traffic density	0.497 to 0.769	< 0.25	0.416 to 0.902	< 0.01	0.48 to 0.853	< 0.01

time-distance from which the driver first obtains the resolvable information from the sign depends on the driver's awareness of the legibility of the maximum-sized letters (presumably by extra-foveal vision, which is also generally responsible for the detection of the sign).

Table 3 gives the effects of some important independent variables on the sign evaluation measures. The arrows 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. For example, the first row of the table shows that, in general, as the traffic density increases, (a) T_{used}, T_f, and T_t decrease; (b) T_{max}/T_f decreases; and (c) values of T_e and T_t/T_{used} appear to be unaffected.

In the following paragraphs, some of the important and specific results are presented briefly:

1. The T_{max}/T_f ratio was found to be a good descriptor of the sign utilization by the drivers; if T_{max}/T_f is equal to 1.0, 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. The T_{max}/T_f ratio increases as the visual load on the driver's information acquisition process increases. For the same drivers, the values of the T_{max}/T_f ratio were higher under car-following situations than under open-road situations (Fig. 2). The T_{max}/T_f ratio decreased as urgency in obtaining sign information increased. The values of T_{max}/T_f, in general, were higher for side-mounted signs than for overhead-mounted signs.

2. T_{used} was found to be related in various ways to different factors.

a. T_{used} is 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 (Table 2).

b. T_{used} increases as relevancy of the information presented by the sign in relation to the driver's objectives increases (Fig. 3).

c. T_{used} is related to the driver's visual load due to traffic situations. As the traffic density increases, the time that is available for the drivers to obtain information from the signs decreases (Fig. 3).

d. T_{used} depends on the amount and the type of information the driver needs. T_{used} increases as length of sign message increases. Further, values of T_{used} were smaller when the information required by the driver was displayed on the sign than when the displayed information did not contain the information required by the driver.

e. In a sequence of signs such as X ROAD, EXIT 1 MILE; X ROAD, EXIT ½ MILE; X ROAD, EXIT NEXT RIGHT, the values of T_{used} for the first sign are generally higher than those on subsequent signs, except for the last sign (or signs) where a major control action such as exiting or lane changing is required.

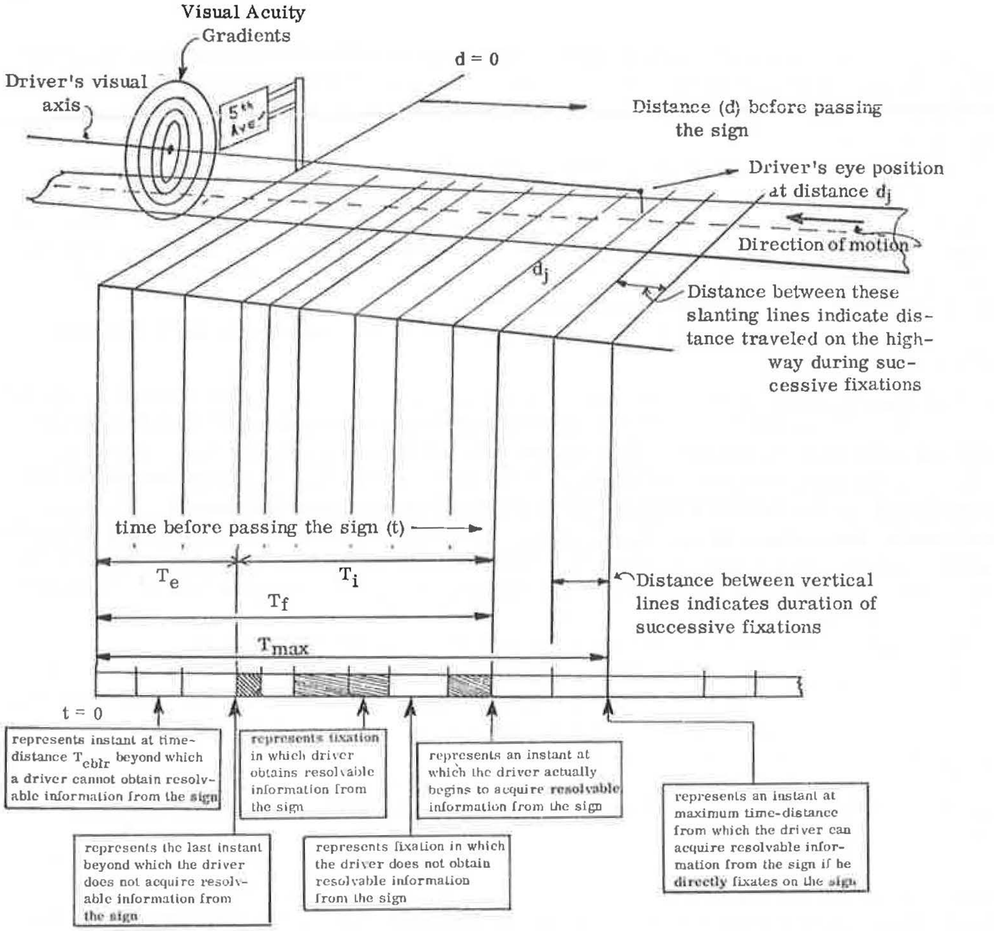
f. When a driver approaches a group of signs, the values of T_{used} are governed by the natural tendencies of the driver in relation to his objectives and positional expectancy of relevant signs and by the fact that a driver who wants to continue on the highway (i.e., in through traffic) generally spends more time looking at the signs on the left side and a driver who wants to exit generally spends more time looking at signs on the right side.

g. As the driver becomes familiar with a sign, he requires less time to obtain information from it. T_{used} is negatively correlated to driver familiarity; but if the signing is inadequate, poor, or confusing at low levels of increasing familiarity, T_{used} decreases as familiarity increases (Fig. 4). (In Figure 4, F1 represents the situation of an unfamiliar driver, and F2 represents the situation of an unfamiliar driver driving the second time on the test route.)

h. Drivers do not just concentrate on a sign (after T_f) until they obtain the required information from the sign but 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_t/T_{used} lie between 3.00 and 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.

Figure 1. Measures used to define sign-reading behavior of drivers from eye movements.



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 2. Effect of traffic density on T_{max}/T_f.

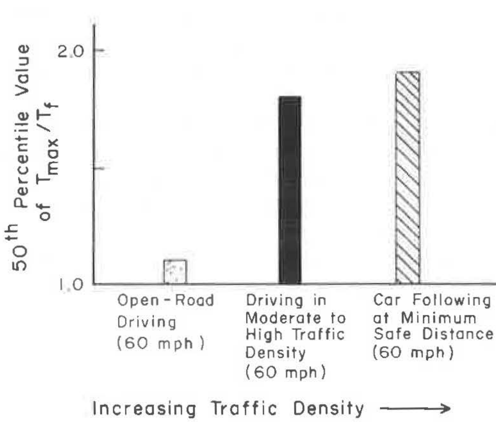
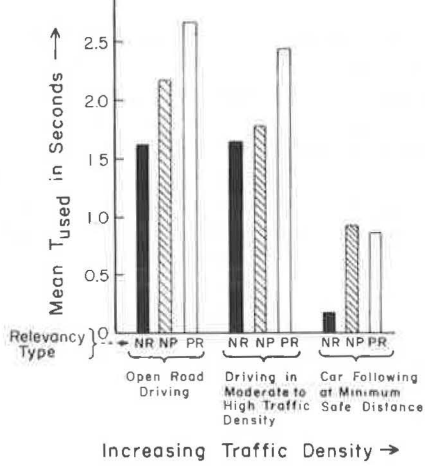


Figure 3. Effect of signing relevancy and traffic density on T_{used}.



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

3. The minimum time necessary to acquire required information from a sign is related to different variables.

a. T_{min} decreases as driver familiarity increases.

b. T_{min} increases as the amount of message read by the driver increases (Fig. 5). (In Figure 5, IN1 = searching for the mileage number for a given destination, IN2 = searching for a given destination when it was displayed along with other destinations, and IN3 = searching for a given destination when it was not displayed on the sign.)

c. When a driver is looking for specific information (e.g., a destination, the minimum time necessary to obtain such information depends on the position of that information on the sign. Drivers, in general, read the signs from top to bottom. Therefore, if the required information is displayed on the top line, T_{min} is the smallest.

d. In general, less search time is required when the information needed by the driver is presented on the sign than when the required information is not presented on the sign (Fig. 5). Further, when a driver is searching for specific information on a sign, the minimum time necessary to search and acquire the information increases as the amount of words and lines displayed on the sign increases (Fig. 5).

4. A negative for (T_{used} - T_{min}) indicates either that the driver read only a partial message from the displayed message on the sign or that the driver is familiar with the highway or read more completely the preceding signs.

5. When a verbal response to signing was requested from the subjects, their sign reading in the laboratory correlated to their sign reading on the road. But the road-sign reading generally requires about 300 msec additional time. Further, the sign-reading behavior of drivers under normal conditions (i.e., when the drivers were simply asked to follow a given route) is different from their behavior when they are asked to verbally report the information concerning the given route. The difference is due to a difference in a driver's strategy in reconfirming or reassuring himself about the message on the sign.

6. The sign-reading behavior of drivers on unfamiliar roads where the signing is confusing (or contradictory) and inadequate had the following characteristics: high values of T_{max}/T_f (more than 2.0); low values of T_t/T_{used} (less than 2.5); and very low values of T_e (approximately equal to T_{emin}).

PROJECTED IMPLEMENTATION OF THE RESULTS

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

When all the results obtained in this research are assembled, they suggest that the most important variables associated with determining the degree of match between a sign and the sign-reading behavior of 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_{emin} (defined as the minimum time-distance from which a driver can obtain information from the sign),
3. T_{min} (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).

Those 4 variables, when further analyzed in relation to the following variables, provide detailed information on how a driver shares or uses the time period (T_f - T_{emin}): difference between T_{used} and T_{min}, T_t/T_{used}, (T_f - T_{emin})/T_{min}, and relations between T_f and T_{max} when considered by the ratio T_{max}/T_f. The last variable provides information about the driver urgency and use of the sign information availability.

Table 3. Effect of increase in value of independent variable on sign evaluation measures.

Number	Independent Variable	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 to driving task	↑ 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	Urgency associated with obtaining information from sign	NC-NA	↑ F-4	NC-NA	NC-NA	↓ F-4	NC-NA
5	Driver's 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 sign from path of vehicle	↓ F-4	↓ F-2 F-4	↑ F-4	↓ F-4	↑ F-4	NAE
7	Location of sign in 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 sign in group of (multiple) signs	→ F-7	→ F-7	→ F-7	→ F-7	→ F-7	→ NAE
9	Awareness of 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 sign and message complexity	↑ F-4 F-5 L-1 L-2 L-3	NA-NC	↓	↑	NA-NC	↓

Note: UA = unaffected; NAE = no apparent effect; NC = not considered; NA = not applicable; ↑ = 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); and alpha-numeric notation by arrow = study in which effects were observed.

Figure 4. Effect of driver familiarity on T_{used}.

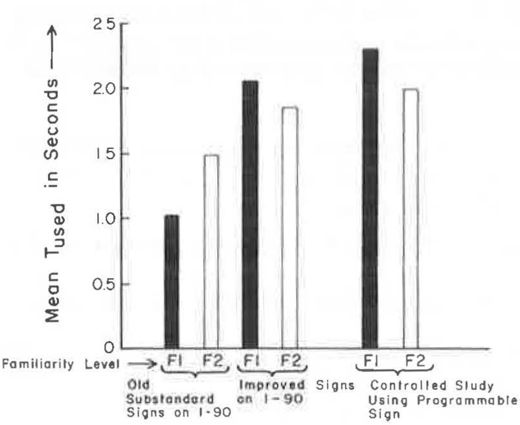
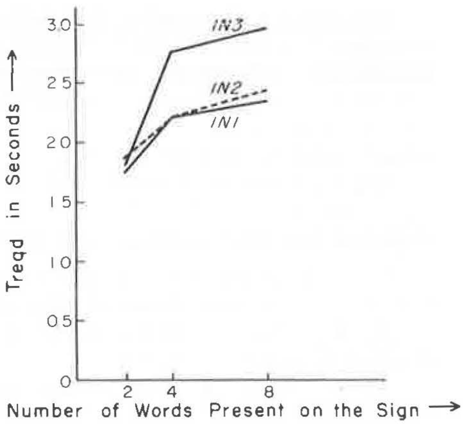


Figure 5. Minimum sign information acquisition time as affected by length of message and driver's information need.



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, (a) the ratio T_{used}/T_{min} should be close to 1.0 (under higher visual loads); (b) the ratio T_t/T_{used} should be large, i.e., at least more than 3.0; and (c) the ratio T_{max}/T_f should be close to 1.0.

An increase in T_{max}/T_f indicates decreased use of the availability of the visual information displayed by the sign. Further, smaller values of T_t/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, a ratio T_{used}/T_{min} smaller than 1.0 indicates partial reading.

Because there exist intersubject and intrasubject differences in the sign-reading behavior of 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 for the sign to be evaluated data on sign-reading behavior of many subjects be collected and, based on the characteristics of the distributions of the measures developed above, inferences on the "goodness" or "adequacy" of a sign 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 values of criteria such as K_0^*, K_1^*, . . . , K_4^*:

1. Evaluation of information availability (estimate of the probability that $T_{max} \geq K_0$);
2. Evaluation of sign utilization and driver urgency (estimate of the probability that $T_{max}/T_f \leq K_1$);
3. Evaluation of the completeness of sign reading (estimate of the probability that $T_{used} \geq K_2^*$ (K_2^* can be selected as a suitable percentile value of the T_{min} obtained from the distribution of T_{min});
4. Evaluation of the time-sharing process (estimate of the probability that $T_t/T_{used} \geq K_4^*$);
5. Estimate of K_3^* - K_4^*, where K_3^* is the theoretically computed value on the estimate of the time-sharing process by the equation $K_3^* = (T_f - T_{emin})/T_{min}$.

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

In this research the data on the sign-reading behavior of drivers under many different driving situations were obtained to gain an understanding of 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 the design of a road sign so that the characteristics of the sign would be matched with the sign-reading behavior of the drivers under the traffic and highway situations existing in the vicinity of the sign.

Current highway signing standards presented in the Manual on Uniform Traffic Control Devices for Streets and Highways do not provide sufficient information to a highway engineer for designing highway signs. The design guidelines in such manuals only make a highway engineer aware of considerations such as use of safety factors to account for driver information and time associated with reading the sign.

Many of the findings of this research are still too exploratory in nature to provide quantified information on many such considerations, which are currently described merely as guidelines and have mathematical explicitness in the Manual on Uniform Traffic Control Devices. However, the findings strongly suggest that further research would lead toward the development of more mathematical and practical guidelines.

For example, some of the findings of this research offer solutions in the following directions in sign design based on sign-reading behavior of drivers:

1. This research has shown that, under normal traffic conditions and lower visual loads, the 50th percentile values of T_{max}/T_f lie in the neighborhood of 1.5; under higher visual loads (due to higher traffic density), the 50th percentile values of T_{max}/T_f tend to lie over 2.0. That result clearly indicates that, if the sign designer considered the driver's sign-reading behavior, he 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 depends on factors such as length of message displayed on the sign and type of information need of the driver. Therefore, based on this research and future research in this area, some estimates of T_{min} and T_{used} can be provided to a highway engineer for better design of signs.

3. This research has also shown that drivers do not just concentrate on the sign to obtain information but share time with the sign and other objects. Therefore, standard values of T_i/T_{used} for different driving and signing conditions can be established for better design of the signs.

The discussions above were presented only for the purposes of illustration. It appears that a more complete and detailed implementation of this research would lead toward developing schemes and guidelines for both the evaluation and the design of road signs. Currently, further research in this area is under way at the Ohio State University to implement the results obtained in this research and to develop an operational tool that can be used by a highway engineer to solve the signing system design and evaluation problems.

CONCLUSIONS

Two major conclusions can be derived from the research. The first is that concrete proof has been provided to the research community that an eye-marker camera system is a valuable research tool among many other systems available today for the study of highway signing under actual driving situations. Second, the eye-movement data collected in this research have, for the first time, provided quantitative information on the driver's sign-sampling behavior. The data clearly show that, in general, drivers do not just concentrate on a sign (i.e., read a sign in one glance) but rather make several glances to it. The time-sharing process of the drivers with the signs and other objects on the road is found to be dependent on factors such as time-distance to 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, and driver familiarity. Such data on sign-reading behavior of drivers under actual driving conditions were previously nonexistent. Further investigations into the results obtained in this study would no doubt lead to the development of better tools or assessment techniques for both the design and the evaluation of highway signs. Research in that direction is currently under way at the Ohio State University.

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DISCUSSION

M. M. Zajkowski, Wayne State University

The research reported by Bhise and Rockwell represents an important innovation in highway safety research technology. Especially significant is the utility of the eye-marker camera system for evaluating a multitude of variables that may affect the availability or acquisition of guide-sign information. The authors have suggested that because eye movements are involuntary they are relatively bias free when compared to other driving performance parameters. Although some saccadic eye movement is relatively automatic and involuntary, eye-movement patterns seem to reflect a systematic sampling of environmental information, and the sampling is based on the driver's interpretation of incoming sensory information (7). This suggests that eye movements not only may be involuntary but also may be under the influence of current stimulus conditions and past experiences of the driver.

An additional point of some importance is related to the notion of using eye movements as the dependent variable in evaluating sign-reading behavior. It is quite apparent that frequency, pattern, and duration of eye movements reflect the impact of environmental, target, and subject variables on the information-search process. Therefore, it is reasonable to assume that eye movements provide an index of information availability. However, the relation of eye movements to the central information process of the driver is less clear. Thus, it would seem important to make a distinction between information availability and information acquisition. It seems logical to conclude that if an individual fixates on a guide sign the information contained on that sign will be available to him to the extent that it is legible and interpretable. One can be relatively certain that items have been acquired only if the driver is required to make decisions based on that information or if it can be inferred from his behavior that subsequent changes are correlated with informational input. In any event, eye movements constitute a critically important mediating process in the chain of events between the presentation of information and the response to it. Equally important is the authors' conceptual model of the components of this mediating process, their development of eye-marker system designed to provide meaningful data, and their development of the SEADEM program for analyzing the data.

In discussing the criteria of sign adequacy, the authors suggest that unused time should be as small as possible and that the ratio of the time of information availability to the time required by unfamiliar drivers to extract information from signs should be greater than or equal to the ratio of perceptual time sharing to the time that the sign information forms a reasonable image on the retina. Those criteria are appropriate given that sign adequacy is equated with the efficient use of information-display time. However, in concurrence with points made earlier, it is felt that such criteria would represent an extremely important but partial set of evaluative standards by which to assess the adequacy of signs. One must include measures of correlated decision-making and driving behaviors in order to have a complete picture of sign adequacy.

The results obtained by the authors are important in several respects. First, the relations between critical variables for highway research and information-search processes have been quantified by the use of a dependent variable that is unique in that it sensitively reflects both situational and psychological factors. For example, an examination of the summary table of results reveals that increasing the values of the situational factors of traffic density, sign angular location, and sign complexity generally has a negative impact on the sign evaluation measures; that is, available information is not used effectively. Likewise, as a driver becomes familiar with a roadway, he is less likely to attend to sign information. It is interesting to note that increasing the value of sign relevancy, driver urgency, and sign and legibility awareness is related to a more effective use of information. Those variables might well be classified as psychological. Location of sign, position of sign, and information need also seem to be correlated with the evaluation measures but are less amenable to interpretation. Those results would seem to suggest, as many earlier authors have pointed out, that psychological variables that affect driving performance have too often been ignored in design and evaluation of guide signs. This study clearly identifies the importance of those variables and provides a means of quantifying and evaluating them.

The second important aspect of the results is related to the specific utility of the various sign evaluation measures. As the authors have pointed out, T_f (maximum time-distance from which a driver actually begins to acquire reasonable information) is the key variable in evaluation and design of road signs because of its impact on the information-search process. T_{emin} (minimum time-distance from which driver can obtain information), T_{min} (minimum time necessary for the driver to obtain required information), and T_{used} (time during which a driver obtains or can obtain information from a sign) are also considered important variables because when used in various types of analyses one can determine how a driver utilizes the period of time in which the sign information is available to him. The authors then use those values to establish the characteristics of good signs. Stated verbally rather than in the ratio form used by the authors, the maximum time-distance during which the sign can form a reasonable image for an unfamiliar driver should be of such a value that

1. The amount of time spent fixating on the sign should approximate the minimum time required for an unfamiliar driver to extract the required information;
2. The amount of time spent fixating on the sign should be significantly less than the time required to perform other time-shared driving tasks; and
3. The time-distance of the first resolvable fixation should be the same as the time distance when the sign information can first provide a resolvable image.

Those criteria are critical and obviously related to the assumption that effective highway signs must perform their communication function with a minimal disruption of driving behavior. However, it might be desirable to assess the ultimate validity and reliability of those criteria in future studies by expanding the conceptual model to include various kinds of driving behavior that might serve as correlates of the visual behavior described in this paper.

In summary, the authors have developed an innovative and pragmatic method for the evaluation of highway guide signs. Future applications and refinements of the technique will undoubtedly serve to validate the logic of this approach. One is struck by the possibility of additional applications of such a model, and we shall be looking forward to reports of such applications.

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Donald A. Gordon, Federal Highway Administration

The Bhise and Rockwell paper represents an important piece of research. The eye is the point of entry of most information from the highway environment. The visual stimulus is the initial incident in the chain of events that leads finally to the driver's steering and braking reactions. We are, therefore, fortunate that during the past 4 or 5 years, Rockwell and his associates at Ohio State University have concerned themselves with studying the driver's eye fixations. That is no easy task, as those of us who have tried to record eye movements in the accelerating and jolting car can attest. In the latest phase of their work, Bhise and Rockwell have applied eye-registration techniques to the evaluation of signs. Their paper presents the findings of this phase and comprises results of 8 field and 3 laboratory studies.

BASIC CONTRIBUTIONS OF EYE-MOVEMENT STUDIES

Before discussing the contributions of this work to the evaluation of signs, I would like to mention some of the basic findings. In developing their assessment tool, Bhise and Rockwell first had to understand how the eye operates in obtaining road information. The basic factors that affect eye movements had to be taken into account in interpreting the results.

Eye-movement studies by early investigators, such as Javal, Dodge, and Judd, go back almost a hundred years. Those studies showed that the eye does not move in a continuous sweep as it seems to the viewer but rather exhibits long fixations interrupted by short saccadic (jump) movements of about $1/20$ sec. The fixations last about $1/2$ sec each. The early studies also showed an amazing compensation by the viewer's eye for head movements and time-phased movements of convergence and divergence. I mention this early work because the findings of eye-movement studies have always been fascinating and somewhat unexpected.

Bhise and Rockwell's basic contributions concern the effects of driver and sign characteristics on eye movements. They have shown that eye fixations reflect the driver's familiarity with the sign, his trip purpose, the relevance of the message to the driver's goal, the redundancy of the signs, and the size of the sign letters. Some of their findings are given to illustrate the novelty of this work:

1. Although drivers spend more time viewing a sign whose message is relevant, nonrelevant guide signs are also fixated. The authors show that the majority of freeway guide signs are actually looked at by the driver as he passes.
2. The driver spends more time viewing a sign when the information he is looking for is absent than when it is present.
3. The driver starts to view the sign relatively later when traffic is heavy than when traffic is light. His fixation is also delayed when he is closely following another vehicle.
4. If the driver gets relevant information from an advance warning sign, he spends less time viewing subsequent signs than he would otherwise.
5. Although the driver spends less time scanning a familiar sign than an unfamiliar sign, the difference in times is less than one might expect.
6. The driver sometimes takes less time than he needs in viewing the sign. The comparison is with minimum times found in laboratory studies of sign viewing.

These are some of the basic findings of these studies. Earlier phases of this work were concerned with fixations during the process of learning to drive and with the effects on visual fixations of alcohol and fatigue. The virtue of all the work is that the conclusions flow from and are supported by quantitative performance data.

APPLIED CONTRIBUTIONS

The main purpose of these studies was to develop a method of evaluating signs. To do this, the authors evolved a set of measures of the efficiency with which information was obtained from the sign. Those measures are based on time relations. T_{max} is the point in time at which the sign can first be read; T_f represents time at which the driver first fixates the sign; T_t is the total amount of time available to the driver for viewing the sign; and T_{max}/T_f is the relation between the time at which the sign can first be seen and the point in time at which it is actually fixated. A full description of those and other evaluation indexes is given in the report itself. Predictive equations were programmed on the computer to indicate trade-offs among the factors affecting readability. The number of messages, letter size, and sideward positioning of the sign may be mutually arranged to reach a level of adequate readability.

Bhise and Rockwell state that a bad sign is shown by several symptoms: (a) The first fixation occurs much later than necessary, (b) the sign receives an excessive amount of attention, and (c) the sign receives attention even when the driver is very close to it. These symptoms are defined in terms of fixation times. Although it may seem intuitively evident that those measures indicate sign pathology, one would feel more comfortable if their validity was experimentally demonstrated. For example, the contrast of a sign may be systematically decreased. In this case, the eye-fixation times should show more and more pathological symptoms, thus indicating the validity of the symptoms. One also wonders how driver unfamiliarity would affect eye movements. A novel sign, such as an unusual diagrammatic design, will invite a long visual inspection whether or not it is a good sign. Driver unfamiliarity may be overcome in the laboratory by special training on a set of signs similar but not identical to the test signs. It is much more difficult to give this sort of training on the road.

Although eye-fixation techniques are a valuable addition to sign evaluation methods, there are other methods. Signs have been evaluated by Roberts, Kohlsrud, and others in terms of erratic maneuvers. Berger, Gordon, and Zajkowski separately have used a laboratory technique to assess signs. The driver was shown retouched highway pictures that had experimental signs added. He was asked to state as quickly as possible the lane he should be in to reach an assigned destination. That technique provides measures of the time required to extract information from the sign and indications of the correctness of the driver's interpretations as shown by his lane choices. Another assessment technique developed by Mace, Hostetter, and Seguin and perfected by Mast, Hooper, and Chernisky involves projecting signs on a screen in front of the driver. Fictitious signs and exits are used to prevent the effects of driver familiarity. The driver's reaction time, vehicle speed, and acceleration noise are measured by that technique. There are also operational indications of sign failure: drivers stranded on the gore and shoulder of the road and letters of complaint from frustrated motorists. I mention these methods because they seem to have been overlooked or at least not referred to by Bhise and Rockwell. On the other hand, eye-movement techniques for evaluating signs have important potential advantages. They can be carried out in the operational setting, and they involve the visual mechanism by which drivers obtain and use road information.

The Bhise and Rockwell studies raise a number of challenges for all of us, and I think for the authors too. So far, Rockwell and his coworkers in the United States and Keith Rutley in England have been almost the only ones involved in eye-movement work. Many more of us would be involved if we could use the equipment or, better yet, if a simpler registration device was developed. Present methods are fussy and uncomfortable and require the attendance of a trained technician. A number of questions remain to be answered. Are the performance measures so far proposed the most effective for assessing a sign? How do the eye-movement results check with other sign-testing methods or combine with other methods to provide a complete evaluation? What other vehicular-guidance problems can be effectively approached with eye-fixation techniques? There is also need for further review of the work already accomplished. After completing their large-scale program of 11 studies, Bhise and Rockwell must feel a bit by themselves and appreciative of whatever feedback is offered by the traffic engineering community. Novel methods of improving roads and signs do not so often appear. When one does, it benefits us to pay attention and give it a fair and thorough hearing.

Fred Hanscom, Virginia Highway Research Council

The authors are to be commended for an important effort in which they examine some meaningful parameters in relating motorists' performance to highway-signing characteristics. The problem of matching signing with driver behavior is, without a doubt, representative of one of the most critical research needs in the area of motorist information systems. The variables explored in this paper provide much insight relative to driver sensitivity as an optional method to evaluate highway signing; yet, the research should be considered as a basis for an evaluation methodology rather than a completely operational tool.

The focus of this discussion will be on some ideas relative to the integration of eye-marker camera research into the development of sign evaluation methods. Some specific recommendations that relate to work presented by Rockwell and Bhise will be given first, and then some general concepts will be presented evolving from other signing research in light of potential refinements using eye-marker camera techniques. The intent will be to provide some impetus for incorporating advanced human-factors technology into eye-marker camera research.

Although the authors have alluded to many essential considerations, their work still does not constitute a workable tool for the evaluation of highway signs. The presentation of the research for practical interpretation by a traffic engineer should define various driver task-loading situations indicative of different levels of driver attention sharing between the sign-reading tasks and other necessary driving tasks. Various task-loading situations should be delineated according to various levels of traffic density, highway geometry, weather, and similar non-signing-related parameters. Then, for purposes of providing a practical traffic engineering tool, it would be desirable to prescribe signing requirements in terms of maximum number of signs for a given highway section, sign content as a function of information loading, and the like for each of the previously delineated driver task-loading situations.

However, the accomplishment of those steps would involve considerably more research than has been done to date. An interim approach, based on data already collected, could be to provide practical "engineering" guidelines for T_{max}, K_i^*, and other variables as a function of the already observed sign content and driver task loading.

A key to future incorporation of eye-marker camera techniques in the evaluation of highway signs rests in the researcher's ability to define and analyze the driver's information-seeking task. Research by King and Lunenfeld (8) has provided much insight relative to motorists' satisfaction of their information needs. Their analysis of the driving task disclosed that the operations performed by a driver 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 also seen to be related to this hierarchy. It was found that a demanding priority exists in satisfying information needs; microneeds have priority over situational and macroneeds. Satisfying this priority of information needs was said to be basic to the design of a motorist information system.

The systematic approach to the information-seeking process of drivers opens the door to some interesting applications of eye-marker camera research. Of particular interest could be the situation where information at all 3 levels is competing for the driver's attention. Driver response to each of the performance levels can be quantified; hence, verification of the Lunenfeld and King research would be available. Further, a closer examination of the driver attention-sharing trade-offs among the control, guidance, and navigational tasks would be a valuable asset in the development of a sign evaluation criterion.

In a recent follow-up article, Alexander and Lunenfeld (9) asserted that traffic engineers should use the time-sharing trade-offs to locate navigational information at a place where the guidance task is not so complex that low-primacy information cannot be processed. Through use of eye-marker camera techniques and related research, a quantification of the guidance task for a given section of highway could allow a determination of the optimal placement and content of navigational information that a motorist could process. However, the determination of driver task loadings may be difficult for a number of reasons that impose limits on the interpretation of eye-marker camera data. First, spare driver visual capacity often results in eye fixations on irrelevant information. Second, it is difficult to account for the effects of peripheral or extra-foveal vision. A measured fixation may merely represent a meaningless point of focus while the motorist is peripherally acquiring significant information. Finally, there is the problem of a motorist looking at an object but not processing the information.

Although such problems are no doubt inherent in eye-marker camera research, some of the existing difficulties can be resolved with continued effort. One such difficulty, which was cited in an earlier work by Rockwell (10), is that of accounting for intersubject differences resulting from varied idiosyncratic perceptual characteristics of drivers. This problem denotes the obvious need for refined human-factors techniques to be combined with eye-marker camera research.

An interesting approach to provide some insight relative to individual driver difference in perception of highway signs might be the application of "expressive self-testing" principles that have recently been researched by Roberts et al. (11). Their work has demonstrated that certain motivational and attitudinal differences between individuals, which are detectable through questioning techniques, can be used to predict certain biases affecting many motorists' decisions. Of particular interest is the capability of the technique to show differences in perceived danger in a driving situation between groups of high versus low self-testers. The use of that method or related psychological techniques may help explain some of the individual differences that confound the interpretation of eye-movement data.

There is an urgent need to develop more sensitive techniques to evaluate highway signing. The recent acceptance of graphic-signing concepts makes this need more apparent. Current evaluation techniques such as conflicts studies and erratic-maneuver analyses do not provide insight into driver decision-making processes. The authors have provided a significant advancement in the complex process of providing a human-factors approach to determine the impact of signing on the motorist. Suggestions for future research outlined in this discussion include revising the format of the evaluation technique to provide signing standards as a function of driver task loading; using eye-movement data to quantify various components of the driving task; and combining eye-movement results with psychological testing to partially resolve intersubject perceptual differences.

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