

Chapter II

METHODOLOGY FOR THE EVALUATION OF ROAD SIGNS

Introduction

The primary objective of this research study was to develop a methodology that would be capable of evaluating the systems for displaying road sign information to drivers.

The methodology developed in this research project is based on an extensive study of sign reading behaviors of drivers. The sign reading behaviors of drivers were obtained by recording eye movements of drivers under actual driving situations. An eye-marker camera system which works on the principle of corneal reflection was used to collect driver eye-movement data. The description of the system is presented in Appendix B.

The best manner in which to evaluate a road sign and other traffic control devices has long been a subject of controversy. Selective recall is often used but neglects the fact that drivers commit most signing as well as other visual cues to short-term rather than long-term memory. Since many of the highway signs do not require an overt response on the part of the driver and because this information is acquired visually, it appears that the problem of visual information transfer; i. e., how a driver acquires or does not acquire information displayed by a sign, can be best studied by recording driver eye movements. This permits dynamic simultaneous measurement of eye fixations, traffic flow, sign configuration and layout as the vehicle proceeds down the highway. Further, it should be noted that the use of a performance measurement system such as an eye-marker camera results in benefits not realizable with other types of measurement systems. These include:

1. 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.
2. 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 of interest. For example, instructions such as, "Drive in your normal manner and exit at U. S. 62," requires that the driver rely on route guidance and regulatory signing without specifically mentioning any of the signs that are being studied.

The Approach

The problem of evaluating road signs was approached by studying how a driver acquires information displayed by a sign as he approaches a sign. The problem, therefore, is that of evaluation of visual information transfer between a road sign and the moving driver. A road sign, thus, is the source of information and the driver, the receiver. The problem of the evaluation of road signs is, thus, basically that of determination of degree of "match" between the visual information display characteristics of a sign and the visual information acquisition characteristics of the driver.

The visual information transfer between a sign and driver cannot be studied effectively by consideration of characteristics of signs and visual information acquisition characteristics of drivers independently, and simultaneous consideration of all characteristics of the system, including road signs, highway, driver, traffic and other related conditions such as visibility is necessary.

The visual information that a traffic sign can display, when viewed by a driver from different locations (from different distances and angles) on the highway would mainly depend upon the following variables:

1. location of the sign with respect to the highway,
 - a. distance of the left edge of the sign from the right edge marker on the highway (lateral position), and
 - b. height of the lower edge of the sign from the surface of the road,
2. size of the sign,
3. sizes of letters and symbols,
4. contrast of the sign with the visual background on the highway,
5. contrast of the letters with the sign,
6. length of the message, and
7. geometric design of the highway before a driver passes the sign.

The visual information that can be available to a driver from a given sign would depend upon the following considerations:

1. characteristics of driver's vision (mainly, visual acuity in the binocular field of vision),
2. driver's location and path of motion,
3. vehicle speed,
4. time available to acquire and process the visual information available (to interpret displayed message on the sign),
5. relevancy of the message in relation to driver objectives,
6. complexity of the message,
7. familiarity with the sign,
8. level of visual load present due to traffic and highway characteristics, and
9. attentiveness of the driver.

Further, the visual information transmitting medium; i. e., the driver's visual environment introduces limitations on the visual information transfer. The following problems, therefore, need consideration in determination of visual information transfer between a sign and a driver:

1. visibility conditions,
 - a. due to rain, snow, fog, etc.,
 - b. day and night, and
 - c. glare,
2. effect of highway geometry on visibility, and
3. blockage of signs by other vehicles.

Measurement of Sign-Reading Behavior of Drivers from their Eye Movements

In this research, the sign-reading behavior of a driver was measured by analyzing every single fixation that a driver makes as he approaches a sign. The analysis centers around determination of all eye fixations in which the image of a sign on the driver's retina provides "resolvable" information such that information from the image can be extracted by the driver when needed. The visual information

displayed by a sign can, therefore, 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 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).

An analytic expression for the above criterion for the determination of resolvability of letters on the sign is, therefore, as follows:

$$\frac{\gamma(t)}{5.5 \alpha [\eta(t)]} \geq 1$$

where

t = time-distance of the driver from the location of the sign (i. e., the driver requires t seconds to pass the sign). (See Figure 2.1.)

$\gamma(t)$ = angle subtended by the height of the letter at the driver's retina when the driver is at time-distance t from the sign (measured in minutes).

$\eta(t)$ = eccentricity angle of the image of the letter formed on the driver's retina at time-distance t .

Note: Eccentricity is the angle between the driver's visual axis (i. e., eye fixation) and the line joining the center of the letter and the cyclopean eye position of the driver.

$\alpha [\eta (t)]$ = resolution angle (i. e. , reciprocal of visual acuity) measured in minutes of arc in the driver's visual field at eccentricity angle $\eta (t)$.

It should be noted that in this research values of $\alpha (\eta)$ for every test subject were obtained on the basis of their visual examination of their visual fields. The considerations involved in obtaining values of α as a function of η are presented later on pages 69 to 72.

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

From the above inputs, for every successive driver eye fixation, 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 2.1.)

$T_{\max}$ = maximum time-distance from 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.

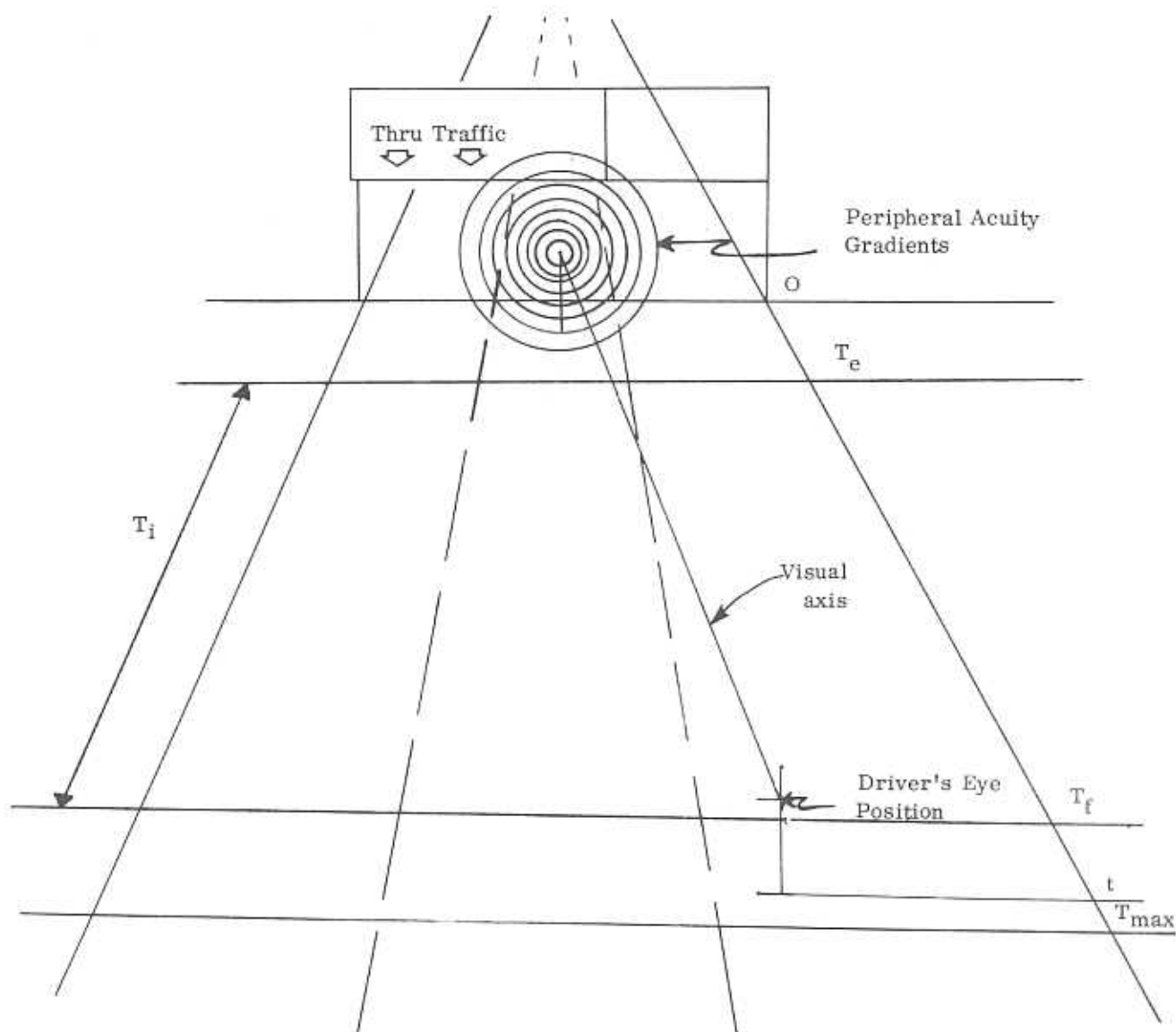
T_f = time-distance at the beginning of the first fixation when the largest letter (or number) on the sign forms a resolvable image on the driver's retina.

- 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.
- 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_{reqd} = minimum time required to acquire the information displayed by a sign. (Note: The information necessary to investigate this measure is generated by conducting controlled experiments. See studies F-5, L-1, L-2, and L-3.)

Figure 2.1 shows a perspective of a three-lane highway and an overhead mounted sign. The figure shows that the driver is driving in the right lane and he is at time-distance t seconds from a sign. The four evaluation measures (i.e., T_{max} , T_f , T_i , and T_e) are shown in this figure. It should be noted that all time-distances are measured from the plane of the sign (i.e., where the driver just passes the sign). When t is greater than T_{max} , resolvable information from the sign cannot be available to the driver even if he foveally fixates on this sign. When t is equal to T_{max} , the driver can only obtain resolvable information from the sign if he fixates foveally on the sign. As t becomes smaller than T_{max} , the driver can make increasing use of his visual field (i.e., sign reading with higher eccentricity angles) to obtain resolvable information from the sign). The measures T_f , T_e , and T_i depend upon the driver's scanning patterns in the time interval between 0 and T_{max} . T_f defines the maximum time-distance at which the resolvable information would be actually available to a driver, whereas, T_e defines the last time-distance and the end of the last fixation in which resolvable information from the sign would be available to the driver.

The SEADEM computer program first determines T_{max} (a detailed description on the computation for T_{max} is provided in Chapter III). The computer program also analyzes every single fixation made by the driver before he passes a sign and from the stored information about the location of each fixation, location of the sign, the path of the vehicle and the visual acuity of the driver, the program determines whether or not the image of the sign formed on the driver's retina would be resolvable.

Figure 2.2 presents a time diagram to provide a physical interpretation of each of the measures defined earlier. The diagram shows duration of 18 successive fixations made by a driver before passing a sign. Let us assume that by observing driver eye-movement data on film, eight out of 18 fixations were



Note: The concentric circles indicate the "decreasing" levels of peripheral acuity around the foveal fixation point of a subject driver's eye.

Figure 2.1.--Relation of Visual Variables to Physical Attributes of the Highway Environment

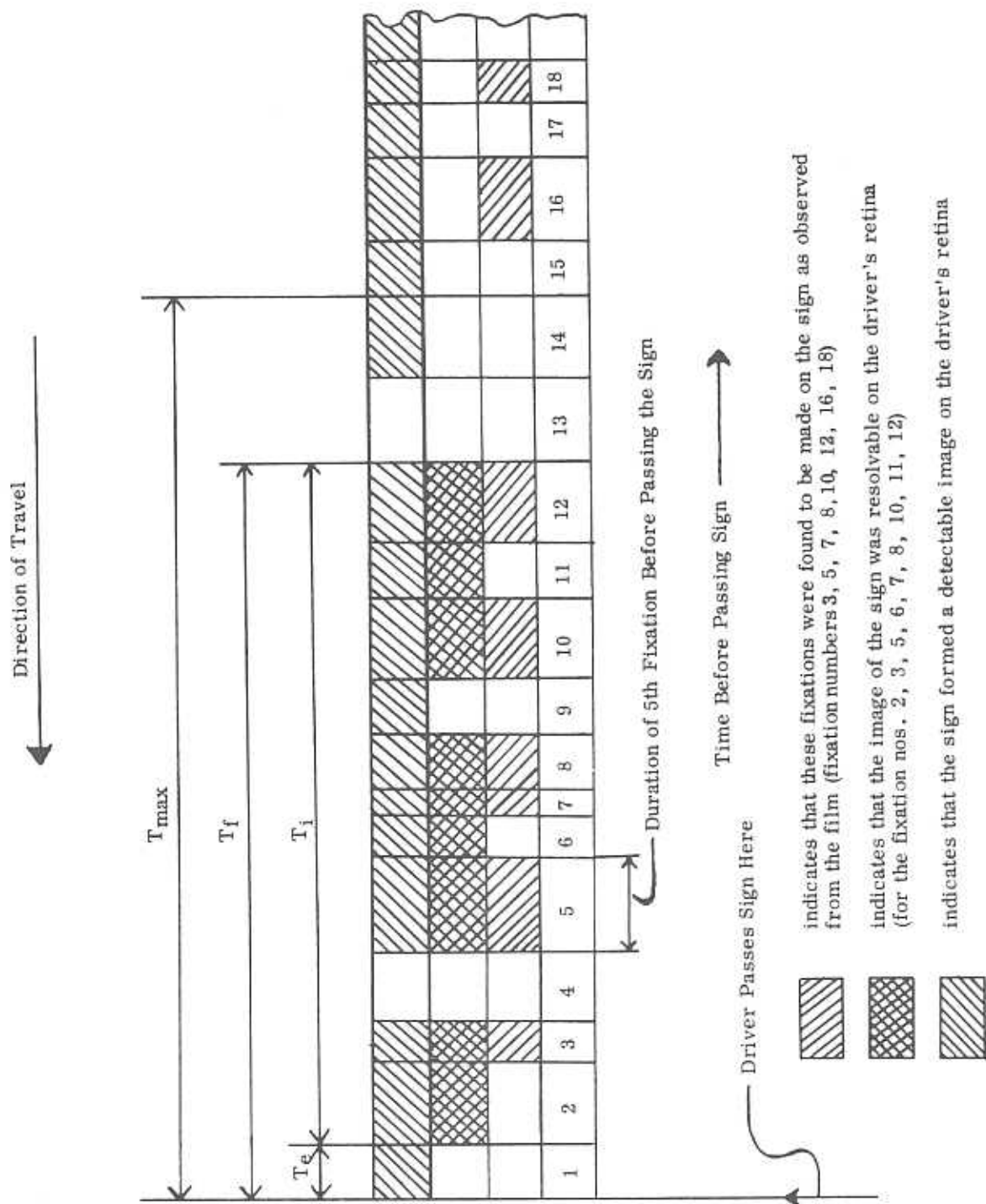


Figure 2.2. --Time Diagram of Eye Fixations of a Driver Before Passing a Sign

found to be made on the sign. The eight fixations can be identified as the fixations bearing the following numbers: 3, 5, 7, 8, 10, 12, 16, and 18. By knowing the velocity of the vehicle, his lane position, location of the sign, and letter size, $T_{\max}$, the maximum time-distance from which the largest letter on the sign (when foveally observed) is resolvable, can be calculated. Therefore, the fixations on the sign beyond $T_{\max}$, namely, fixation numbers 16 and 18 by this driver, would not have given him resolvable information, and, therefore, these fixations can be considered to be fixations made in attempting to detect or locate the sign.

By observing the angular location of all the fixations in the resolvable information availability interval; i. e., between 0 and $T_{\max}$, and calculating the angular location of the center of the sign, the eccentricity angle between each of the fixations can be determined, and, hence, all the fixations can be checked to determine if, during any of the fixations, the image of the sign formed on the driver's retina would provide him with resolvable information. Let us assume that fixation numbers 2, 6, and 11 were additional fixations (for which eccentricity angle $\eta \neq 0$) during which resolvable information from the sign was available to the driver. This provides a method to determine T_{used} . T_{used} , therefore, is the sum of fixation durations during which resolvable information from the sign was available to a driver. The value of T_{used} , in this case, can then be obtained as follows:

$$T_{\text{used}} = \sum_{j \in J} \text{Dur} (j)$$

where

J = set of fixations numbered (2, 3, 5, 6, 7, 8, 10, 11, 12), and

$\text{Dur} (j)$ = duration of the j^{th} fixation.

T_f , according to definition, is the 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_f , in this case, as shown in Figure 2.2, is the time-distance at the beginning of the twelfth fixation. T_e , similarly, can be shown to be the time-distance at the end of the second fixation.

The above 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:

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

$$\begin{aligned}
T_{\text{used}} &= g \text{ (traffic characteristics, familiarity, complexity of message on the sign, highway geometry),} \\
T_f &= h \text{ (sign detection, urgency of information, traffic characteristics, visual acuity, height of largest letter),} \\
T_e &= k \text{ (complexity of message, familiarity, } T_f, \text{ height of the largest letter, relevancy of message), and} \\
T_{\text{reqd}} &= l \text{ (complexity of message, familiarity, relevancy of message).}
\end{aligned}$$

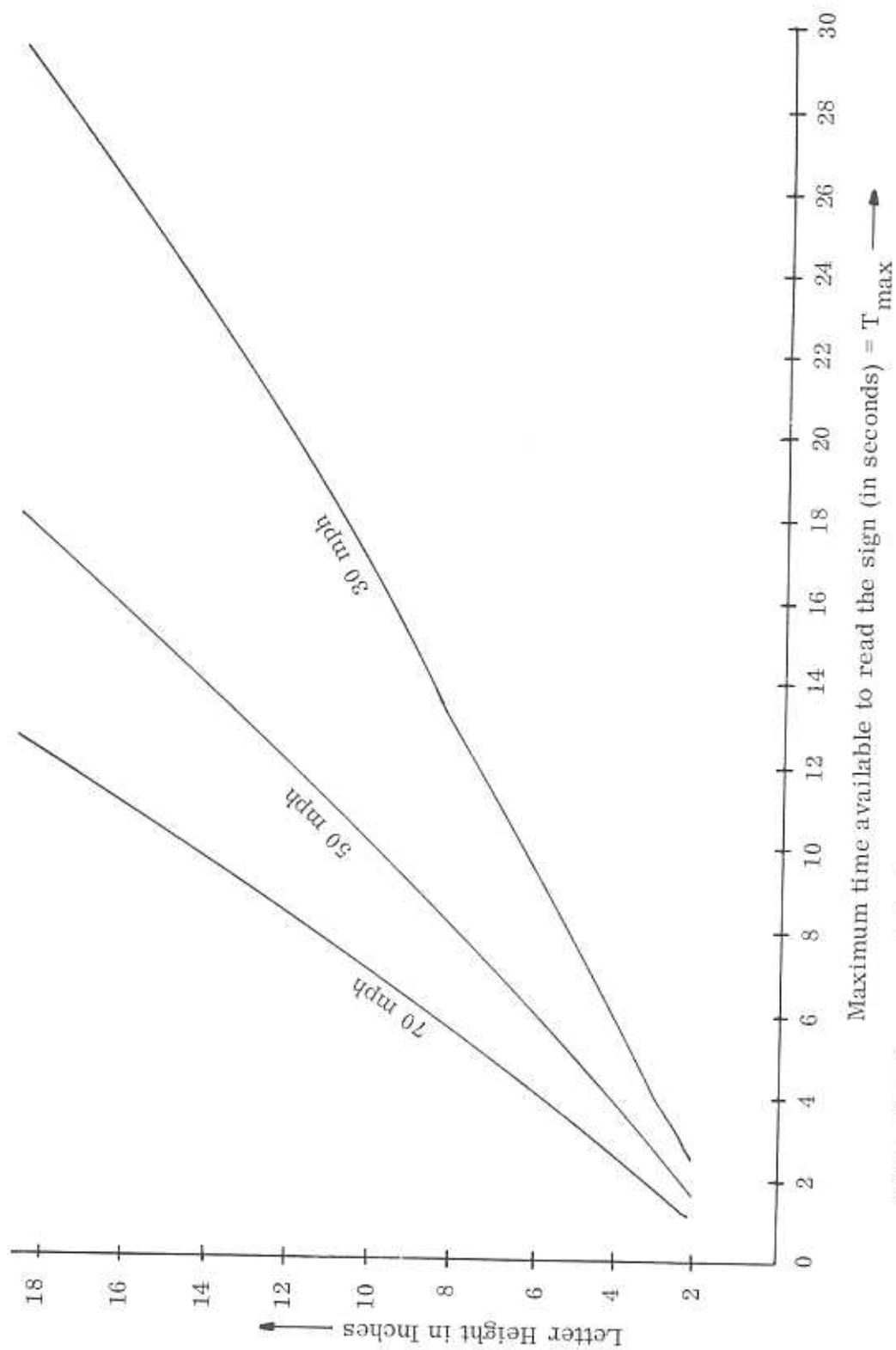
Figure 2.3 illustrates how T_{max} is functionally related to letter height and vehicle velocity. In addition to the above two variables, the values of T_{max} , such as those presented in Figure 2.3 depend upon location of the sign with respect to the driver and the driver's visual acuity. The data presented in Figure 2.3 is for a side-mounted sign and for a driver with 20/20 vision driving in the right lane as shown in Figure 2.4. It should be noted that the values of T_{max} plotted in Figure 2.3 are computed on the assumption that the vehicle velocity is constant. Further, assuming that the velocity of the vehicle, as the driver approaches a sign, is constant, the product of T_{max} and the vehicle velocity would give an estimate of the maximum legibility distance (measured along the direction of travel and assuming a straight plane road). The generally accepted thumb-rule for determining legibility distances for daylight operations of 50 feet per inch of letter height when compared with the resolution criterion considered in this research approximate closely to a driver with 20/30 binocular foveal visual acuity. Therefore, while comparing values of legibility distances obtained by such a thumb-rule with the values of T_{max} presented in this report, the reader should not overlook the fact that values of T_{max} presented are computed on the basis of the following data:

1. binocular visual acuity of the test driver, and
2. the actual velocity profile of the vehicle as the test driver approached and passed the sign.

In addition to the measures presented in the earlier pages, another measure T_{eblr} was found to be helpful in understanding and explaining the sign reading behavior of drivers. The measure T_{eblr} was defined as the minimum possible value of T_e ; i.e., it is the minimum time-distance from which it is possible for a driver to read the sign (i.e., the image of the sign is not sufficiently blurred to be read).

The measure T_{eblr} is, therefore, a function of the following variable,

1. velocity of the driver,
2. location of the sign with respect to the vehicle's path,



Note: The above graph is for a driver with 20/20 vision driving in the right lane and for the sign placement shown in Figure 2.4.

Figure 2.3. --Effect of Letter Height and Vehicle Velocity on T_{max}

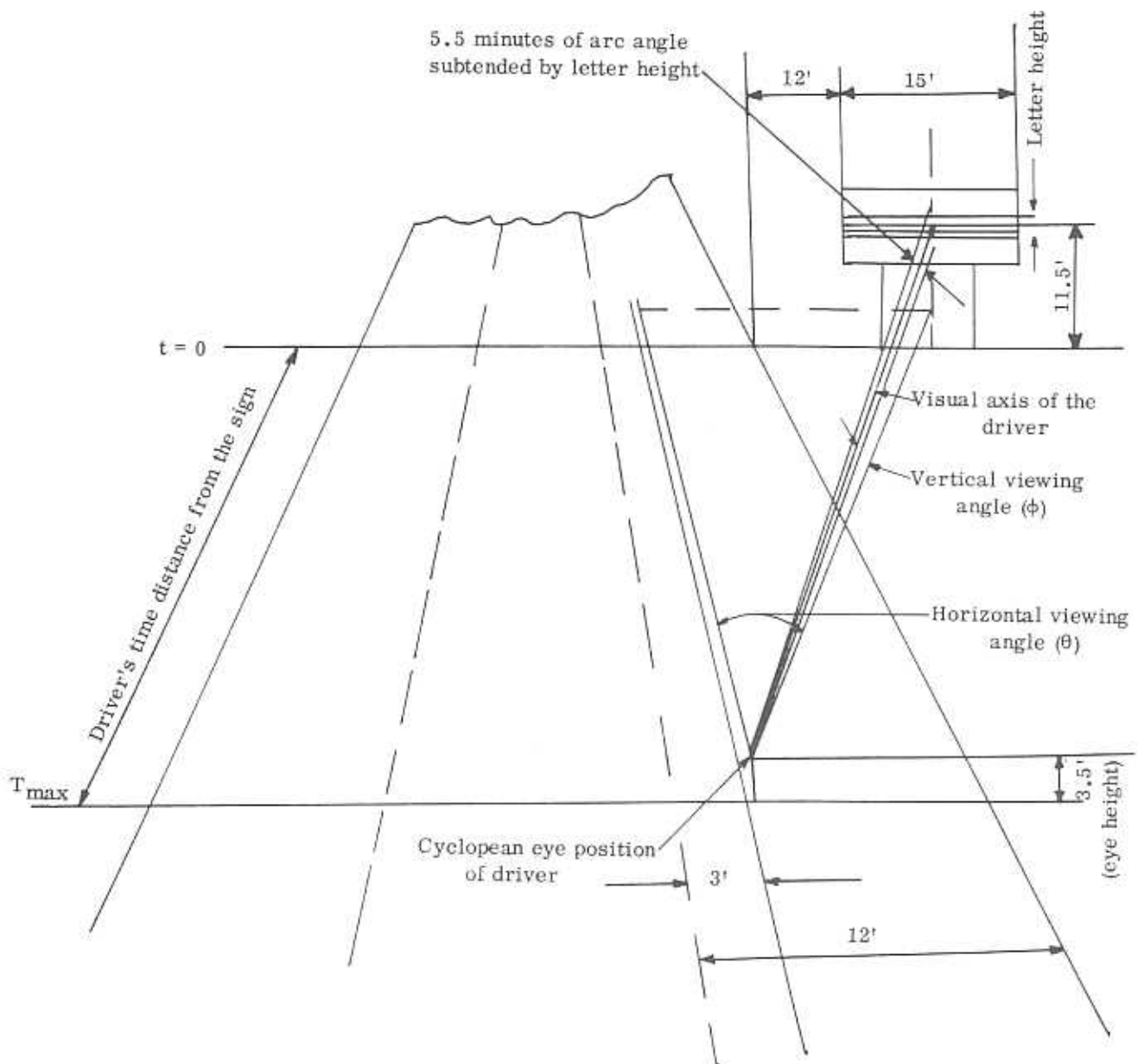


Figure 2.4.--Perspective of Highway Showing Geometric Configuration of the Location of the Sign with the Driver for Computation of the Values of T_{max} (shown in Figure 2.3).

3. sizes of the letter (or symbols) displayed on the sign, and
4. dynamic visual acuity of the driver.

It should be noted that the determination of T_{eblr} is dependent upon the clarity (or resolution) of the image of the sign as the driver drives past the sign. The limit of resolution due to the blurring of the retinal image is considered to occur at angular velocities higher than 100 degrees/second (1.74 radians/sec.) (Yarbus, 1967). Therefore, T_{eblr} can be defined as follows:

$$T_{eblr} = \frac{x}{v} \text{ such that } \sqrt{\left(\frac{d\theta}{dt}\right)^2 + \left(\frac{d\phi}{dt}\right)^2} = v \cdot \left(\frac{y}{r^2}\right)^2 + \left(\frac{zx}{s^2r}\right)^2 = 1.74$$

where

x = horizontal distance between the sign and the cyclopean eye location of the driver,

y = lateral distance between the center of the sign and the cyclopean eye position of the driver,

z = height of the center of the sign from the cyclopean eye height of the driver,

$$s = \sqrt{x^2 + y^2 + z^2},$$

$$r = \sqrt{x^2 + y^2}, \text{ and}$$

v = velocity of the driver (assumed constant).

The time interval ($T_f - T_{eblr}$), therefore, defines the time that is available to a driver to obtain information from a sign after he begins to obtain resolvable information from the sign in the very first fixation from the largest time-distance.

Ratio Measures for Sign Evaluation and Their Interpretation

On the basis of the measures presented earlier the following additional ratio measures were developed for evaluating signs:

1. $\frac{T_{\max}}{T_{\text{reqd}}}$ = sign design evaluation criterion ratio,

2. $\frac{T_{\max}}{T_{\text{used}}}$ = sign information utilization ratio
3. $\frac{T_{\text{used}}}{T_{\text{reqd}}}$ = visual load indicator ratio
4. $\frac{T_{\max}}{T_i}$ = sign reading and time sharing index
5. $\frac{T_i}{T_{\text{used}}}$ = sign information sampling index
6. $\frac{T_{\max}}{T_f}$ = sign information availability utilization and urgency indicator ratio

The above defined ratio measures were developed to enable comparison of relative magnitudes of pairs of different evaluation measures and to study some basic characteristics in the sign reading behavior of drivers.

In general it can be stated that the higher the values of the ratios $T_{\max}/T_{\text{reqd}}$, $T_{\max}/T_{\text{used}}$ and $T_{\max}/T_i$ the better is the sign as the higher magnitudes of these ratios indicate higher amounts of availability of information from the sign to the driver in relation to his temporal informational requirements. Whereas, the ratios $T_{\text{used}}/T_{\text{reqd}}$, T_i/T_{used} and $T_{\max}/T_f$ present information for studying some special problems related to the different combinations of the characteristics of the driver, the traffic situations and the signs. For example, the ratio $T_{\max}/T_f$ gives an indication on when a driver begins to utilize a sign. The values of $T_{\max}/T_f$ closer to 1.0 indicate early utilization, whereas higher values of $T_{\max}/T_f$ indicate less efficient utilization of the sign. Therefore, for a sign presenting relevant information to the driver, higher values of $T_{\max}/T_f$ would mean considerable loss in utilizing available information which may result due to either poor detection characteristics of the sign or inability of the driver in attending to the sign due to higher visual loading conditions (i. e., due to more demanding driving tasks other than sign reading) prevailing in the vicinity of the sign.

In general, a sign can be considered to be adequate if it presents the needed information to an unfamiliar driver with the least amount of driver attention (or distraction) in performing other driving tasks that the driver encounters as he approaches the sign.

Therefore, the amount of T_{used} that is available for a driver to obtain information from the sign should be such that:

1. the ratio T_{used}/T_{reqd} for the sign should be as close to 1.0 as possible (under higher visual loads),
2. the ratio T_i/T_{used} should be large enough such that the driver does not have to concentrate heavily on the sign to obtain the information, and
3. the ratio T_{max}/T_f should be as small as possible.

It should be noted that the smaller values of T_i/T_{used} associated with large values of T_{used} ; i.e., $T_{used} > T_{reqd}$ would indicate increased concentrations of the driver on the sign in his time-sharing process with the sign and the other driving tasks. For an unfamiliar driver, if the ratio T_{used}/T_{reqd} is smaller than 1.0, it would indicate partial sign reading.

Further, the good signs; i.e., signs which can present adequate information with the least driver confusion, would have, in general, the following characteristics:

1. large values of T_{max}/T_{reqd} ,
2. values of T_{used}/T_{reqd} close to 1.0 (note: under low levels of visual load higher values of T_{used}/T_{reqd} could be permissible), and
3. large values of T_{max}/T_i .

This does not suggest that overdesign of signs with redundant sign messages is desired. In fact, since drivers tend to read a large percentage of signs, redundant signs could take valuable perceptual time away from traffic monitoring.