

Chapter V

SUMMARY OF RESULTS, RESEARCH IMPLEMENTATION, AND RECOMMENDATIONS

The purpose of this chapter is threefold:

1. to present and discuss the major contributions made by this research in understanding the sign reading behaviors of drivers,
2. to discuss implementation of the results for evaluating and designing signs such that a proper "match" between the sign reading behaviors of drivers and the signing characteristics is achieved by considering the factors related to traffic and highway characteristics, and
3. to suggest recommendations for further research and applications.

Summary of Findings and Related Discussions

In general, it can be stated that the eleven studies conducted in this research provided results on the effects of different variables related to the characteristics of the signing, the traffic and the driver objectives on the sign reading behaviors of the drivers.

The results at a broader level show the following:

1. the sign reading behavior of drivers is a highly adaptive process; i.e., the manner in which a driver obtains information from a sign heavily depends on the following factors:
 - i. situational visual loads on the drivers visual information acquisition and processing functions,

- ii. driver's informational need,
 - a. type of informational need, and
 - b. urgency associated in obtaining information
 - iii. driver's familiarity with the route,
 - iv. sizes of letters displaying information on the sign,
 - v. amount of message displayed on the sign and its relevancy to driver's informational need,
 - vi. driver's visual capabilities,
 - vii. vehicle velocity, and
 - viii. location of the sign with respect to the path of the driver.
2. It was found that the variable T_f (defined as the maximum time distance from which a driver actually begins to acquire resolvable information from a sign) is the "key" variable for both the evaluation and design of road signs.

The period $(T_f - T_{eblr})$ denotes the time that is available to the driver to read the signs until he passes the sign. It should be noted that T_{eblr} denotes the minimum time-distance from which the moving driver could obtain information from the sign. At time-distances smaller than T_{eblr} the image of the sign on the driver's retina is considered to be blurred such that it is extremely difficult for the driver to obtain legible information from the sign. Therefore, depending upon the driver's informational need, the driver has to adapt his sign reading behaviors in the period $(T_f - T_{eblr})$ to obtain required amounts of information from the sign.

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

- i. It was found that the ratio $T_{\max}/T_f$ increases as the visual load on the driver's information acquisition process increases. It should be noted that the visual load on the driver can be defined as the level of visual information acquisition demands on the driver due to tasks in driving excluding the sign reading task. It was found that the values of ratio $T_{\max}/T_f$ under car-following situations were higher when compared to the values of the $T_{\max}/T_f$ for the same drivers under open road driving situations.
 - ii. The ratio $T_{\max}/T_f$ was found to decrease with increase in driver urgency in obtaining information from the sign.
 - iii. The measures $T_{\max}$ and T_f were found to be significantly and positively correlated indicating that as the driver approaches a sign his awareness of the presence of the coming sign and of the legibility of the sign (i.e., the information received by the driver from the blurred image of the sign in the extra-foveal vision) influences T_f .
4. The measure T_{used} was found to be significantly and positively correlated to T_f , indicating that if T_f is higher, a driver can spend more time in obtaining information from the sign.
 5. It was found that the drivers do not just concentrate on a sign (after T_f) until they obtain the required information from the sign, but they share their time after T_f between the sign and objects on the road. It appears that under normal freeway driving situations; i.e., under low to moderate visual loads, and for adequate signs the driver time-shares with the signs such that the 50th percentile values of T_i/T_{used} lie between 3.00 to 4.00.
 6. 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.
 7. As the relevancy of signing with respect to the driver's informational need increases the values to T_i/T_{used} decrease.
 8. The minimum time required to acquire displayed information from a sign (T_{reqd}) was found to be related to different variables as follows:

- i. T_{reqd} increases with increase in the amount of message read by the driver, and
- ii. T_{reqd} decreases with increase in driver familiarity.
- iii. When a driver is looking for a specific information; e.g., destination, such as how many miles is Eddy Road, the minimum time necessary to obtain such information depends upon the position of that information on the sign. It was observed that the drivers, in general, read the signs from top to bottom. Therefore, if the required information is displayed on the top line, T_{reqd} is the smallest.
- iv. When the information needed by the driver is presented on the sign, the driver, in general, requires less time than if the required information is not presented on the sign.

Further, it was found that when a driver is searching for specific information on a sign the minimum time necessary to search and acquire the information, in general increases with increase in the amount; i.e., words and lines, displayed on the sign.

9. When the difference ($T_{used} - T_{reqd}$) is negative, it would indicate one of the following possibilities:
 - i. driver reading only a partial message from the displayed message on the sign, and
 - ii. familiar driver:
 - a. familiar to the highway, and
 - b. familiar due to more complete reading of the preceeding signs.
10. In general, it was found that the driver under higher visual loads spent less time reading the signs than the same drivers under lower visual loads.
11. The sign reading behaviors of drivers driving on unfamiliar road under "confusing" (or contradictory signing) and "inadequate" signing situations had the following characteristics:

- i. high values of $T_{\max}/T_f$ (over 2.0),
- ii. low values of T_i/T_{used} (less than 2.5), and
- iii. very low values of T_e ; i.e., T_e approximately equal to T_{eblr} .

Implementation of the Results

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

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

1. T_f (defined as the maximum time distance from which the driver first begins to acquire information from an approaching sign),
2. T_{eblr} (defined as the minimum time distance from which a driver can obtain information from the sign),
3. T_{reqd} (defined as the minimum time required for the driver to obtain the required information from the sign), and
4. T_{used} (defined as the time during which the information from a sign is available to the driver).

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

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

3. $(T_f - T_{eblr})/T_{reqd}$,
4. the relationship between T_f and T_{max} , when considered by the ratio T_{max}/T_f , provides information about the driver urgency and utilization of the sign information availability.

Current highway signing standards presented in the Ohio Manual of Uniform Traffic Control Devices for Streets and Highways (revised 1969) do not provide sufficient information to a highway engineer for designing highway signs. For example, for designing Expressway Guide Signs with Varying Legends, the manual (ODH, 1969, revised) on page 135 simply states the following:

For guide signs with varying legend the standards for legibility must be established in terms of letter size. The legibility distances must give the driver sufficient time to read the sign before he has passed it. Although under the best conditions a guide-sign message can be read and understood in a brief glance, a reasonable safety factor must be allowed for inattention, blocking of view by other vehicles, unfavorable weather, inferior eyesight, or other causes for delayed or slow reading.

On the other hand, the usual repetition of directional information on successive signs on the approach to an expressway interchange often gives a driver more than one opportunity to obtain the information he needs.

Regardless of letter size, the legend on a guide sign must be so limited as to be readable during the few moments that a driver can turn his eyes from the road before him. Expressway guide signs, in particular, should be limited to three lines of principal legend on roadside signs, and two lines on overhead signs.

The guidelines such as those illustrated above provide some information to a highway engineer while designing signs. But currently, a highway engineer has no tools (or methods, established procedures, formulae, etc.) available to account for different variables that are suggested in the manuals for the design of the road signs. The manual only makes him aware of the considerations such as:

- a. use of safety factors to account for driver inattention, and
- b. time associated in reading the sign, etc.

The findings of this research have suggested many relationships between sign reading behaviors of drivers, the signing, and the traffic characteristics. Many of the observed relationships, of course, are still exploratory in nature and are not quantified to the degree that they could be immediately implemented in the sign design practices. However, the findings, no doubt, have indicated how and to what extent many of the factors influence the effectiveness of the signs. This study, therefore, could be considered as a first step towards generating information in a more explicit manner on many considerations that are currently merely described as guidelines without any mathematical explicitness in the Manual of Uniform Traffic Control Devices.

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

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

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

2. This research has shown that the time required by the driver to obtain information from the sign is dependent upon the factors such as:
 - a. length of message displayed on the sign, and
 - b. type of informational need of the driver, etc.

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

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

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

A research contract entitled, "Implementing Sign Research Results Into Operational Practices," (Project EES 407B) was awarded to the Systems Research Group of The Ohio State University to continue research work in this area. The specific objective of the research work in Project EES 407B is to implement the results obtained in this research study along with other findings available in the areas related to the problem of developing an operational tool that can be used by a highway engineer to solve the signing system design and evaluation problems. The research work proposed in the Project EES 407B is being aimed at developing a computer model, which will:

1. take into account all the necessary design and operational factors (such as highway geometry, traffic flows in each of the lanes, the range of sign reading behavior and visual capabilities of drivers, etc.) and their relationships, and
2. perform calculations to provide,
 - a. detail signing system design,
 - b. measures describing "goodness" or "effectiveness" of the design, and
 - c. determine costs that will be incurred in building, installing and subsequent maintenance of signs if a signing system designed (or existing design improved) under such specifications is actually put into practice.

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

1. to implement the research results for evaluating road signs, and
2. to implement the research results for design of new signs.

It should be noted that in the last section of Chapter I (Figures 1.9 and 1.10) two possible schemes, one for the evaluation of signs and the other for the design of new signs, are presented. The Final Report of the research project EES 407B which is expected to be ready for publication early in 1973 would present more detailed information on the implementation of the results obtained in the research.

Research Contribution

In addition to the results presented earlier in this chapter, one of the more basic contributions of this research is the presentation of a concrete proof to the research community that an eye-marker camera system such as the one used in this research is the most valuable research tool among many other systems available today for the study of highway signing under actual driving situations. The data obtained in this research by the use of an eye-marker system has provided many insights and relationships between the sign reading behaviors of the drivers and the characteristics of the other components of the highway transportation system. Further research on the basis of the results obtained from this study would no doubt make a significant contribution in achieving a better match between the drivers and the highway signs.

Suggestions for Future Research

In addition to research efforts in this area continued under the research project EES 407B, "Implementing Sign Research Results Into Operational Practices," further research in the following areas is highly warranted.

1. Evaluation of Highway Signing Under Nighttime Driving Conditions

The driver's ability to obtain information from the signs under nighttime differs greatly from the daytime driving conditions. During daytime a driver experiences luminance levels approximately above 3 fL (foot-lambert); whereas, during nighttime the luminance levels range between 4 to 0.003 fL (Schmidt, 1961). The driver's visual capabilities associated with reading signs; i.e., visual acuity, decreases with decrease in illumination levels. For example, the visual acuity of a driver for 76 percent contrast (between object and background) at luminance levels 1 fL and 0.1 fL would be approximately 0.9 and 0.6, respectively. Therefore, in general, under nighttime conditions the information availability of a sign; e.g., measured by the measure T_{max} , would reduce considerably and the signs which are considered to be adequate during daytime conditions may be found to be inadequate under nighttime conditions.

Therefore, it is highly recommended that a similar study under nighttime driving conditions for both non-illuminated signs and illuminated signs; i.e., externally and internally illuminated, should be undertaken. The Systems Research Group has currently developed a new eye-marker system for collecting driver eye-movement data under nighttime driving conditions under another research contract sponsored jointly by the Ohio Department of Highways and the

Federal Highway Administration. This system can be used for collecting eye-movement data of drivers for the investigation of their sign reading behaviors under nighttime driving conditions.

It is obvious that the problem of the evaluation and design of the road sign cannot be considered to be complete until the performance of the signs under both the nighttime and daytime conditions is investigated.

2. Additional Sign Research During Daytime Driving Conditions

The results obtained in this experiment have shown that many variables related different components of the highway transportation systems affect the sign reading behaviors of drivers. Further, since the collection and analyses of the driver eye-movement data is expensive, it was not possible to investigate effects of different variables on the sign reading behavior of the drivers at a greater detail. Therefore, no doubt, a similar study on a larger scale is highly desired. It appears that a future research work should be more concentrated on determining the effects of the following variables on the sign reading behaviors of the drivers:

1. visual loads due to traffic density,
2. lateral positions of signs,
3. highway geometry, and
4. multiple and sequential signing.

Further research on estimating values of T_{reqd} as a function of different variables such as number of words, type of information needs, etc. is also needed.

3. Research Towards Better Utilization of Existing Signs

The research efforts should also be directed in investigating ways and methods in which a driver attention can be attracted towards a sign as soon as he would be able to obtain resolvable information from the sign. In other words, the results obtained from this research show that for a very large percentage of signs the values of T_{max}/T_f lie above 1.0. This means that the drivers do not utilize the information available from the signs during the period $(T_{max} - T_f)$. Thus designing signs such that the ratio T_{max}/T_f would approach the value 1.0 would mean the best possible utilization of existing signs. Obviously from the economic viewpoint, increasing T_f by decreasing the value of T_{max}/T_f (for the same value of T_{max}) would be highly favored over increasing T_{max} (which can be achieved by either decreasing traffic speeds or increasing letter sizes).

Since the values of $T_{\max}/T_f$ were found to increase with increase in visual loads on the drivers, this problem becomes more critical on highways carrying high density traffic flows.

4. Evaluating Diagrammatic Signs

In recent years there is considerable interest in changing over from traditional symbolic signing to the diagrammatic signing. It is recommended that for more objective evaluation of the diagrammatic signs, the approach such as that used in this research should be used for the evaluation of diagrammatic signs.

In this research only one diagrammatic sign was studied in Study F-8. Our results showed that the drivers spent on the average about 6.65 seconds in obtaining information from the diagrammatic sign as compared to 1.76 seconds on the standard symbolic signs on the same route.

It appears that the problems associated in interpreting a diagrammatic sign can be better evaluated under actual driving situations and by using an eye-marker camera system as compared to other available techniques such as laboratory studies, traffic and driver behavior measurements, driver interviews, etc.

5. Research Related to Understanding of the Role of Foveal and Extra-Foveal Vision in Sign Reading

From the evidences of sign reading by the drivers by their extra-foveal vision obtained in this research while developing the computer programs SEADEM I and II, the possibility of the drivers obtaining information from the sign by their extra-foveal vision was incorporated. Further research in this area is urgently needed to determine the amount of information that a driver can extract from a sign in a fixation at different eccentricity angles. Such research should also be oriented towards developing ways and methods for investigating trade-offs between attention in foveal and extra-foveal vision.