Chapter IV

STUDIES ON HIGHWAY SIGNING: DESCRIPTION, DATA ANALYSES AND RESULTS

The purpose of this chapter is to present detailed descriptions and results of the eight field studies and three laboratory studies conducted in this research. The field studies are numbered F-1 through F-8 and the laboratory studies are numbered L-1, L-2, and L-3.

Study F-1

Title: A Study for Developing Data Base on Sign Reading Behaviors of Drivers

Objectives: The primary objective of this field study was to collect driver eye-movement data under different signing and traffic conditions to generate a data base that could be used to enable the development of assessment techniques to relate road sign characteristics to driving performance.

Since prior to this study almost no data was available on the sign reading behaviors of drivers, the following independent variables were considered for this study.

1. Relevancy of signing to the driving task

    a. Relevancy type NR (Not Relevant): Signs that are not relevant; i.e., when a driver does not need information from signs to continue driving on the highway.

    b. Relevancy type NP (Not Pertaining to Route): Signs that are relevant but do not present information pertaining to route (or destination).

    c. Relevancy type PR (Pertaining to Route): Signs that present relevant information pertaining to route (or destination).

2. Type of Mounting

    a. standard side mounted signs

    b. standard overhead mounted signs

3. Visual loading related to traffic conditions

   a. open road driving: This condition can be considered to resemble low levels of traffic densities.

   b. normal car following: This condition can be considered to resemble medium to high levels of traffic density.

   c. car following at minimum safe distance: This condition can be considered to resemble high levels of traffic density.

4. Signing density

   a. low (defined crudely as highways having less than 5 individual directional signs per mile on the average)

   b. high

DESCRIPTION OF THE STUDY

Overview: In this study, eye-movement data and driving-performance data for five subjects were collected on different sections of Interstate 71 under the following two types of instructions.

> Instructions of Type I: Under these instructions, the driver was asked to drive on the highway in a normal manner at about 50 mph until he was given further instructions either to pull over on the shoulder of the highway or to take an exit. The route guidance signs encountered by the driver under the following instructions that were not relevant (NR) for the driver.
>
> Instructions of Type II: Under these instructions the driver was asked to drive in a normal manner at about 50 mph and was asked to exit at a specified exit.
>
> The route guidance signs encountered by the driver while driving under the above instructions (i.e., Type II) thus can fall into the following two categories: a) signs that are relevant but do not present information pertaining to the exit (NP), b) signs that present relevant information pertaining to route (PR).

The above two types of instructions were presented in the following three types of driving conditions:

1. open-road driving,

2. normal car following (In these runs the driver was further instructed to drive behind another vehicle in a normal manner. The lead vehicle usually did not exit at the exit that was specified to the driver under instructions of Type II.)

3. car following at minimum safe distance. (In these runs the driver was further instructed to drive behind a lead vehicle and maintain minimum safe distance. The lead vehicle in these runs did not take the same exit under instructions of Type II.)

Test Route and Signing on the Test Route

For this study two sections of Interstate 71 were chosen. Section I was used for open-road driving runs and Section II was used for car-following runs.

Section I extended from Stringtown Road south of Columbus to U.S. Route 41, also south of Columbus. This section of roadway consists of two lanes of pavement in each direction. The road handles low density traffic with the exception of rush hours when traffic density is appreciably greater. Signing on this section of roadway is mounted along the side of the road. A typical sequence of signs designed to furnish information about a freeway exit on this section of roadway normally consists of three signs. These include:

1. A large side mounted sign located one mile from the exit indicating the name of the exit, the route identification of the exit road, and the fact that the exit is one mile away. Some of these signs also include lower panels which indicate how far away the next exit beyond the one immediately ahead is located.

2. Another large sign mounted beside the road shoulder indicating the name of the exit, the route identification of the exit, and an arrow indicating a move to the right is necessary in order to take the exit. These signs are normally positioned about .15 miles before the exit.

3. Finally, a small sign located in the gore area features the word, EXIT, a sequential exit number and an arrow indicating that a move to the right is necessary in order for the driver to make the exit.

In addition to these signs, all of the exits have a fourth sign (located between the first and second signs described above) which indicates whether gas, food, or lodging are available at the next exit. These signs are mounted beside the road shoulder. An example of this type of signing sequence is shown in Figure 4.1. Each of the signs on this section of freeway occurs by itself (i.e., the message furnished by one sign is presented at a time when no other sign can be read, although in many instances the next sign can be seen). An exception to this occurs with the last two signs in the sequence. When the driver is still capable of reading the sign located about .15 miles from the gore area, he becomes able to read the EXIT sign located in the gore area. The signs of this sequence were, therefore, considered to occur in areas of "low signing density."

In contrast to this area of "low density" signing, the Section II chosen for the study had "high density" signing. This area consisted of a section of Interstate 71 within the boundaries of the city of Columbus, Ohio, and running from Fifth Avenue to the northern intersection of I-71 with I-270. Traffic density on this roadway is moderately heavy through the day and extremely heavy during the rush hours at the beginning and the end of the working day. Sequential signing for purpose of indicating a given freeway exit is mounted on overhead supports for the most part. As on the rural section of I-71 described previously, information is presented in steps.

A normal design of signing for an exit on this section of freeway would include the following signs:

1. An overhead sign indicating the presence of an exit 1/4 mile to 1 mile ahead.

2. An overhead sign indicating the presence of an exit and an arrow to indicate that a move to the right is necessary to make the exit.

3. A sign in the gore area indicating the presence of an exit and an arrow indicating that a move to the right is necessary to make this exit.

In addition to these signs, other signs are present which indicate next exits, lanes for thru traffic, and the exits to take for places such as The Ohio State University and Port Columbus International Airport. An example of the signing encountered at one of the exits on which data were collected on this section of highway for Phase I of the research is given in Figure 4.2. (Note: The sign sequence presented in Figure 4.2 is encountered where the driver is exiting at 17th Avenue.)

Figure 4.1. --Typical Sequence of Route Guidance Signs Encountered on I-71 South of Columbus in Study F-1

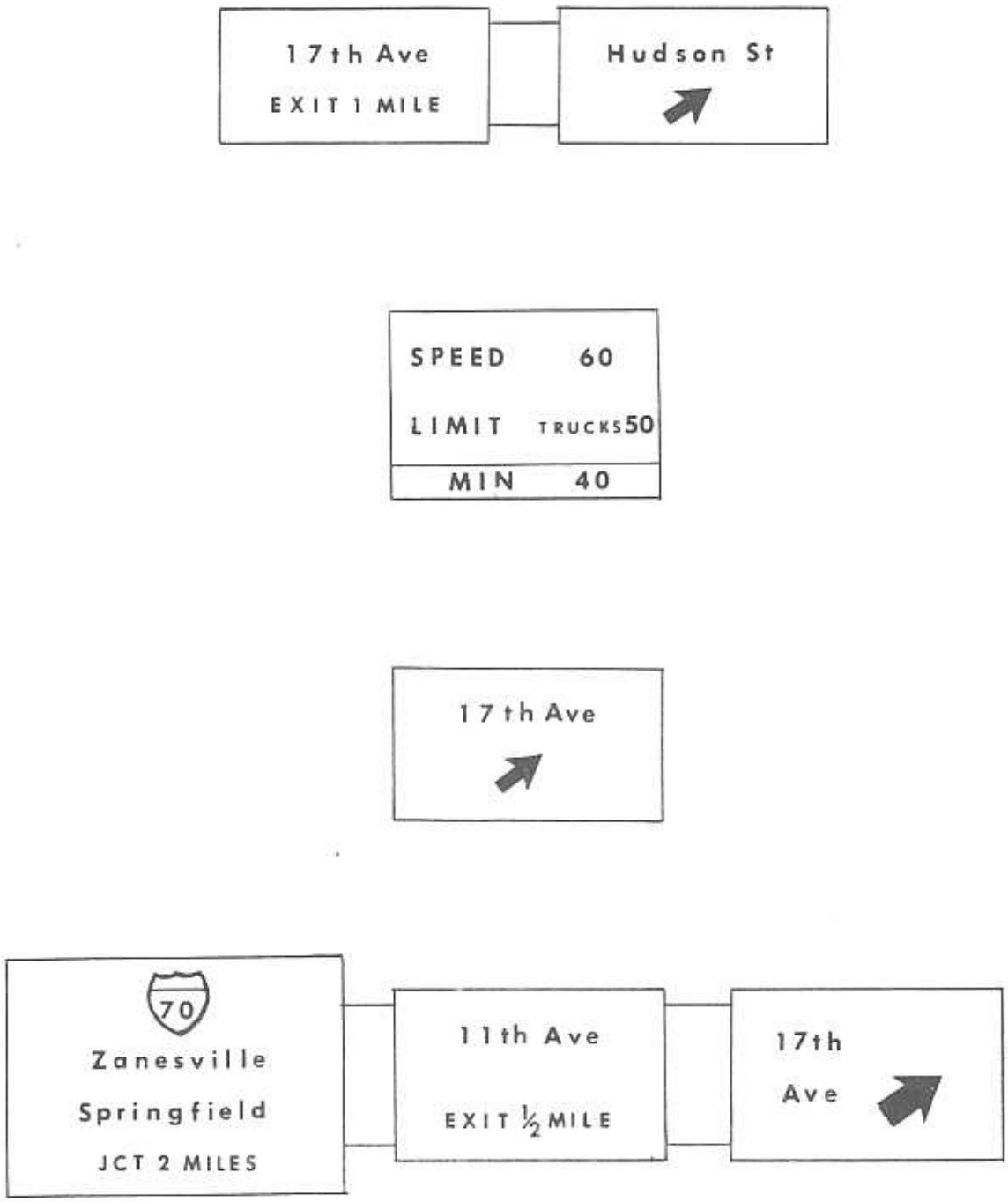


Figure 4.2.--Typical Sequence of Route Guidance Signs Encountered on I-71 in Columbus, Ohio

For purposes of the research, the signing on this portion of the freeway was considered to occur in an area of "high density signing" (i.e., more than one sign was usually available to be read at any one time).

Summary of Test Runs

The test runs conducted on the above two sections of the interstate highways can be summarized under three driving types of driving environmental situations (or driving conditions); i.e., A, B, and C, as shown in the matrix in Figure 4.3.

In this study twenty test runs were conducted for each subject. Out of the twenty test runs, ten were conducted in driving condition of type A and five test runs were conducted in both B and C types of driving conditions. A run included all the signs that a driver encountered while traveling under a specified set of instructions.

For example, one of the runs in type A driving condition consisted of a study of sign reading behavior of subjects for the signs on I-71 (south) between Stringtown Road and U. S. Route 62 exit. In this run, a subject entered the freeway at Stringtown Road and was given the following instructions.

> We would like you to drive this car as you normally would at about 50 mph on this section of freeway and exit at the U. S. Route 62 exit. If you desire to change lanes, tell us and we will let you know if it is safe to do so. Are there any questions?

Any questions that the subject drivers had were answered as concisely as possible. The portion of the instructions concerning the lane changes was included to prevent the subject from making excessively large head movements while wearing the eye-movement camera equipment.

These instructions required the driver to pass the S. R. 665 exit before encountering the U. S. Route 62 exit. The signing for S. R. 665 was considered to be of type NP because it indicated to the driver that no change in performance was required while the signing for U. S. 62 was considered to be of type PR because it indicated to the driver that he should leave the freeway. (Note: In these instructions and all other instructions employed in this research the word "sign" was not mentioned but the drivers were required to process road sign information.)

A more detailed description of the instructions, signs on the test route and experimental conditions in this study are presented in Appendix C of the interim report on this project.

		Type of Driving - Environmental Situations								
		A			B			C		
		Test Section I (Low Signing Density)			Test Section II (High Signing Density)			Test Section II (High Signing Density)		
Driving Situation →		Open Road Driving			Normal Car Following			Car Following at Minimum Safe Distance		
Relevancy →		NR	NP	PR	NR	NP	PR	NR	NP	PR
SUBJECTS	1									
	2									
	3									
	4									
	5									

Figure 4.3.--Matrix Depicting Combination of Independent Variables Used for Test Runs in Study F-1

The data collected in the twenty runs for each subject were later categorized to obtain information corresponding to each of the cells of the matrix in Figure 4.3.

Results

The data obtained from all the test runs was analyzed by using SEADEM I to obtain sign evaluation measures and ratios. The sign evaluation measures and ratios were further analyzed to determine the effects of different independent variables considered in this study, and the results are discussed below.

1. The Effect of Visual Loading Due to Traffic Density on the Sign Evaluation Measures

Figure 4.4 presents the values of means and medians of the measures T_e, T_f and T_{max} obtained by aggregating data collected over all signs and for all subjects in the driving conditions of type A, B, and C. The data presented in Figure 4.4 clearly indicates that the car-following situations; i.e., conditions B and C have a marked effect on T_f than the remaining two measures, when compared with the data obtained under conditions A. Statistical analysis of the data on T_f showed that T_f is significantly smaller ($p < 0.001$, considering t-tests) under car-following situations when compared with open road driving situations.

On the basis of the above finding it can be stated that with increased visual loads due to car-following; i.e., at higher levels of traffic density, the drivers tend to begin to acquire information from the sign late; i.e., T_f decreases, as compared to the open road driving situations.

2. Correlation Between Sign Evaluation Measures

In order to determine relationship between the basic sign evaluation measures; i.e., T_e, T_f, T_{used} and T_{max}, correlation coefficients for the three conditions were evaluated.

The important results obtained from the correlation analysis are presented in Table 4.1. The interpretation of the results presented in Table 4.1 suggest the following:

1. The amount of time that is available for a driver to obtain information from a sign; i.e., T_f, is significantly correlated (and increases) with T_{max}. It should be noted that T_{max} is primarily a function of the following variables:

    a. the driver's visual capabilities,

    b. maximum letter size on the sign,

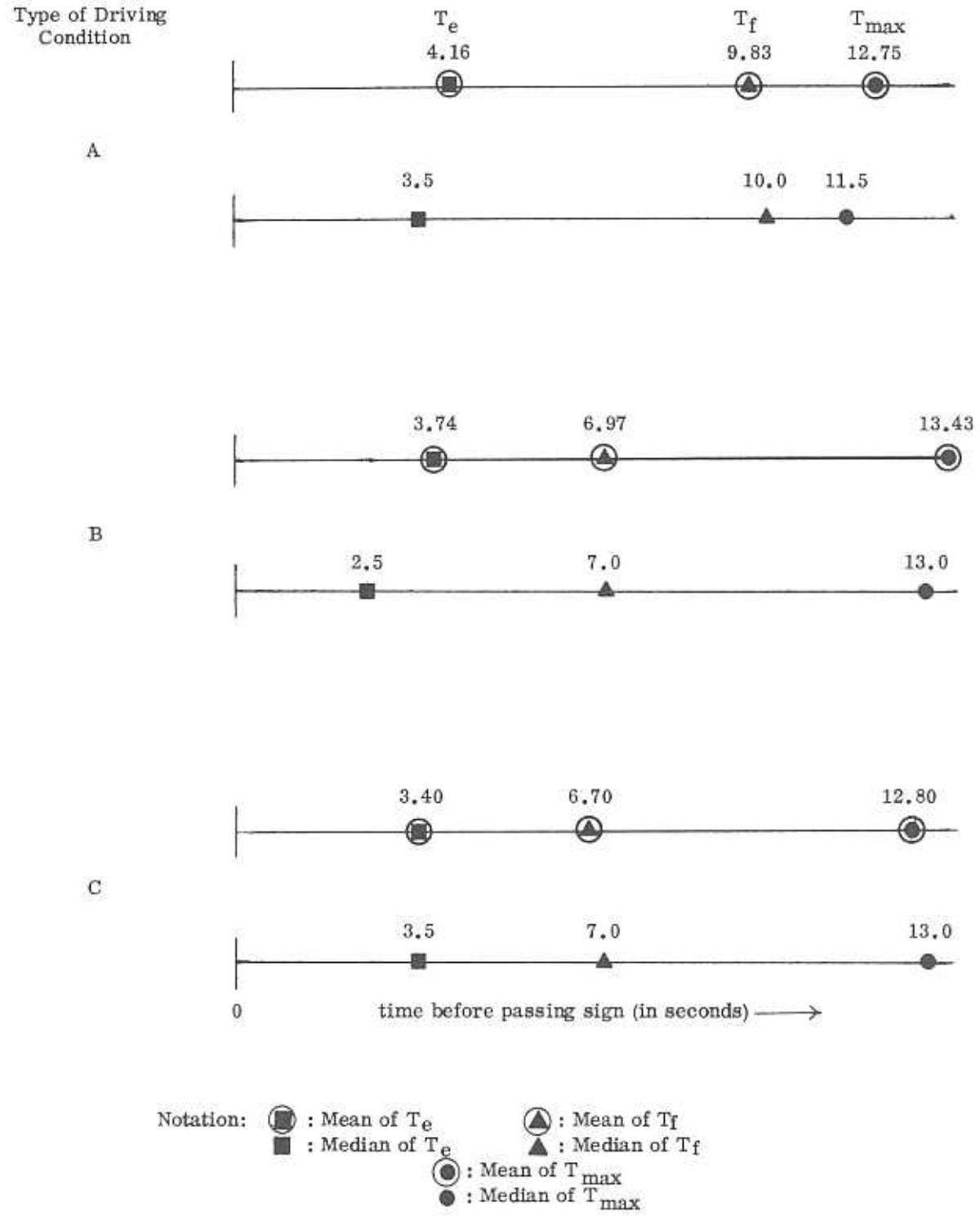


Figure 4.4.--Means and Medians of T_e, T_f, and T_{max} Obtained by Aggregating Data for All Subjects for All Signs in the Driving Situations of Type A, B, and C in Study F-1

c. velocity of the vehicle, and

d. the location of the sign with respect to the driver's path.

2. The measure, T_{used}, is significantly and positively related to T_f and it is independent of T_{max}.

3. When the above two findings are considered concurrently with the previous finding that T_f decreases at increased levels of traffic density, it is evident that T_f is the most important variable in both; i.e., in the understanding of the sign reading behaviors of drivers and in the evaluation of signs.

Therefore, in order to gain more insight into the sign reading behaviors of drivers, the distributions of each of the variables were obtained.

Figures 4.5 through 4.8 present 15th, 50th, and 85th percentile values of the measures T_{max}/T_f, T_{used}, T_i/T_{used}, and T_e, respectively. Observation of the percentile values presented in the above mentioned figures suggest the following.

1. With increase in visual loading T_{max}/T_f increases and T_{used} decreases. (See Figures 4.5 and 4.6.)

2. The measures T_i/T_{used} and T_e do not appear to be influenced (in any noticable trend) by the type of driving conditions. In other words, it appears that the time-sharing behavior of the drivers and the time distance at which they STOP time-sharing with a sign is much more stable as compared to the effect of driving conditions (or loading) on T_f.

The variability in the above data can be further attributed to the following two factors:

1. sequential aspects of signing, and

2. type of relevancy of signs with respect to the driving task.

Table 4.1

Correlation of Sign Evaluation Measures

Measures Correlated	Correlation Coefficients for driving conditions types:		
	A	B	C
T_{max} and T_f	0.3291**	0.2973*	0.2412**
T_f and T_{used}	0.3077*	0.3780*	0.5334***
T_{max} and T_{used}	-0.0466	-0.1069	-0.16025

Note: i) Sample sizes used for computing the above correlation coefficients (ρ's) ranged between 30 to 75.

ii) Hypothesis tested

H_0: $\rho > 0$ vs H_1: $\rho \leq 0$

Notation of significance levels

*: $p < 0.10$

**: $p < 0.05$

***: $p < 0.001$

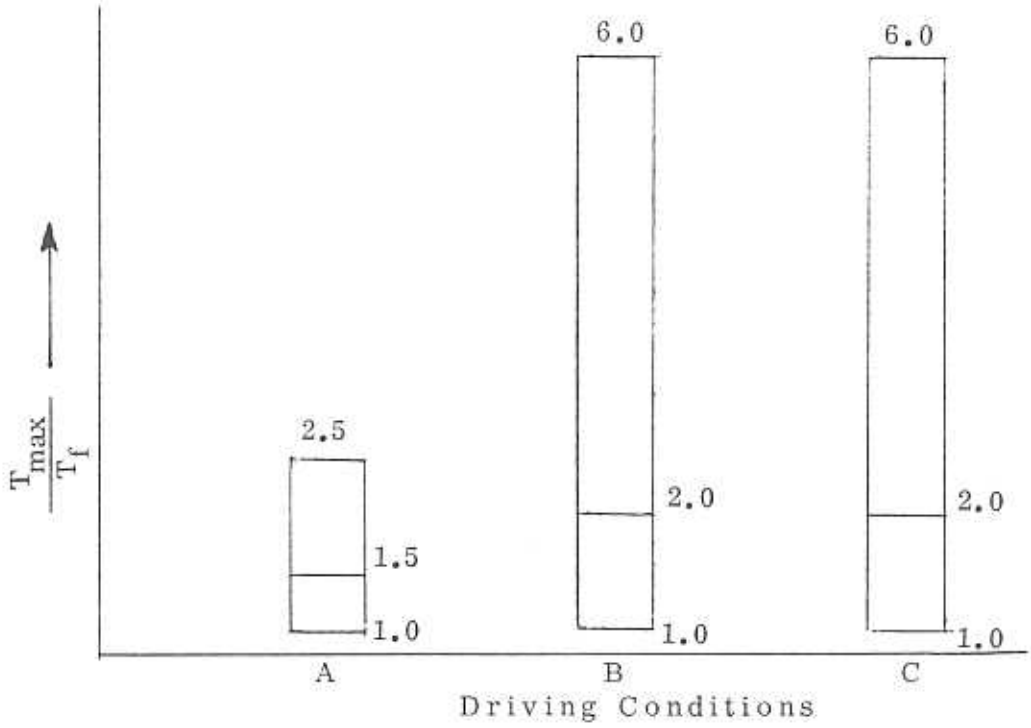


Figure 4.5.--Effect of Driving Conditions on the 15th, 50th, and 85th Percentile Values of T_{max}/T_f

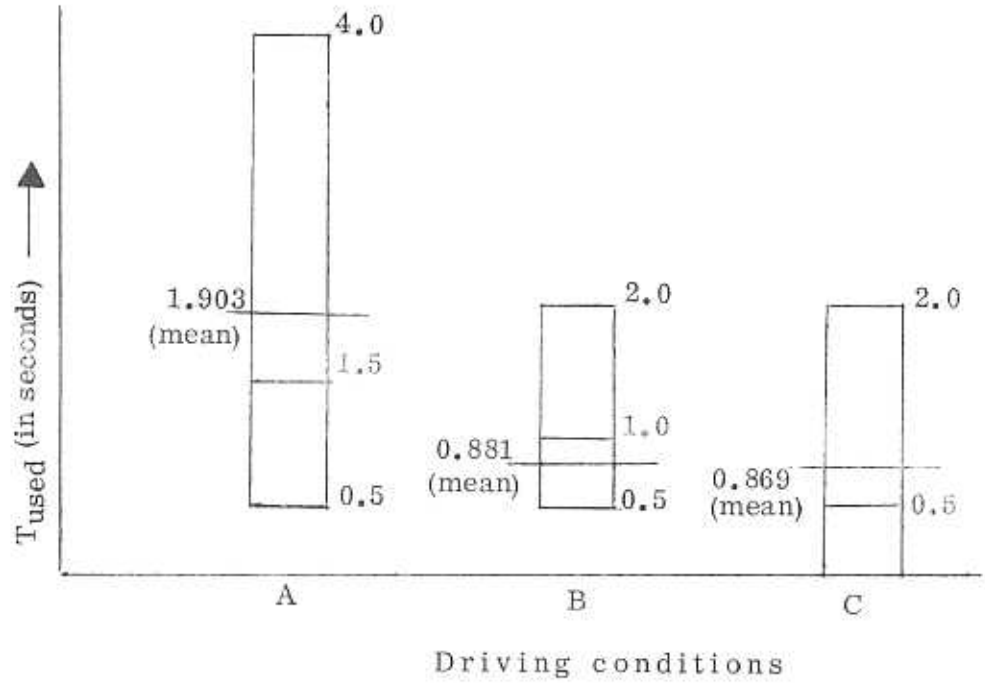


Figure 4.6.--Effect of Driving Conditions on the 15th, 50th, and 85th Percentile Values and Means of T_{used}

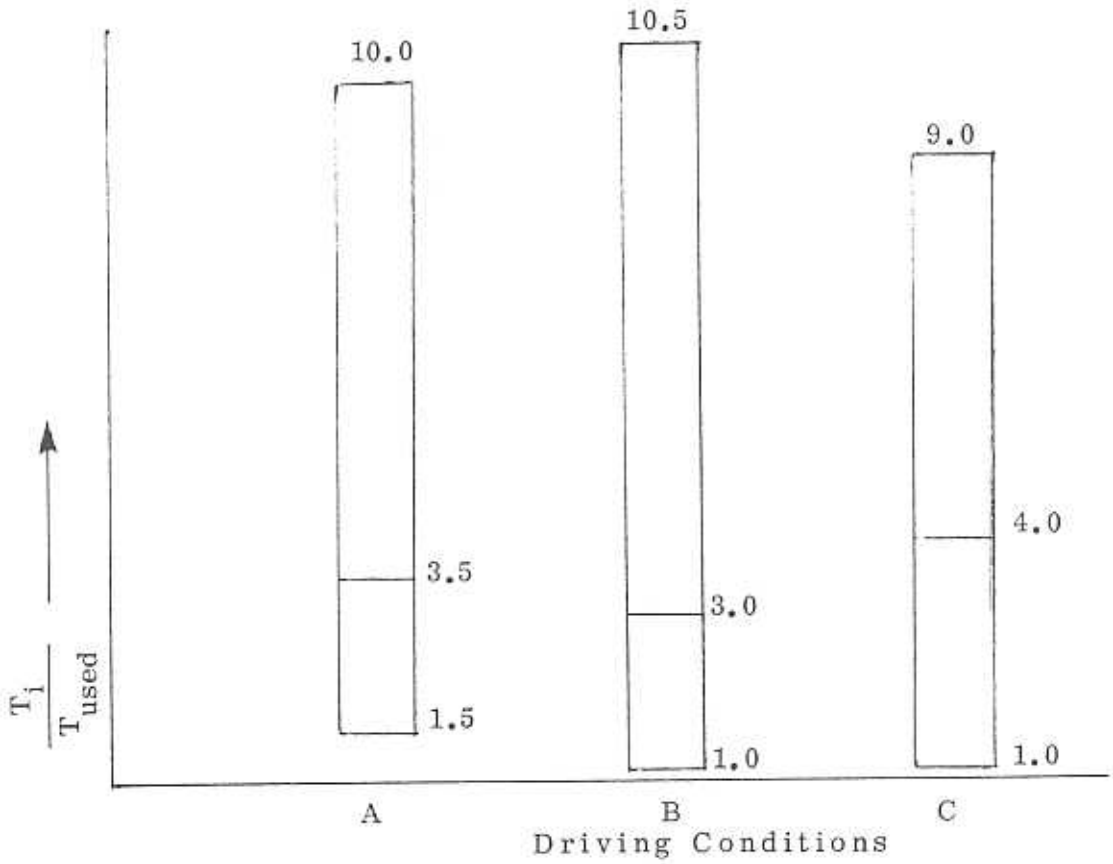


Figure 4.7.--Effect of Driving Conditions on the 15th, 50th, and 85th Percentile Values of T_i/T_{used}

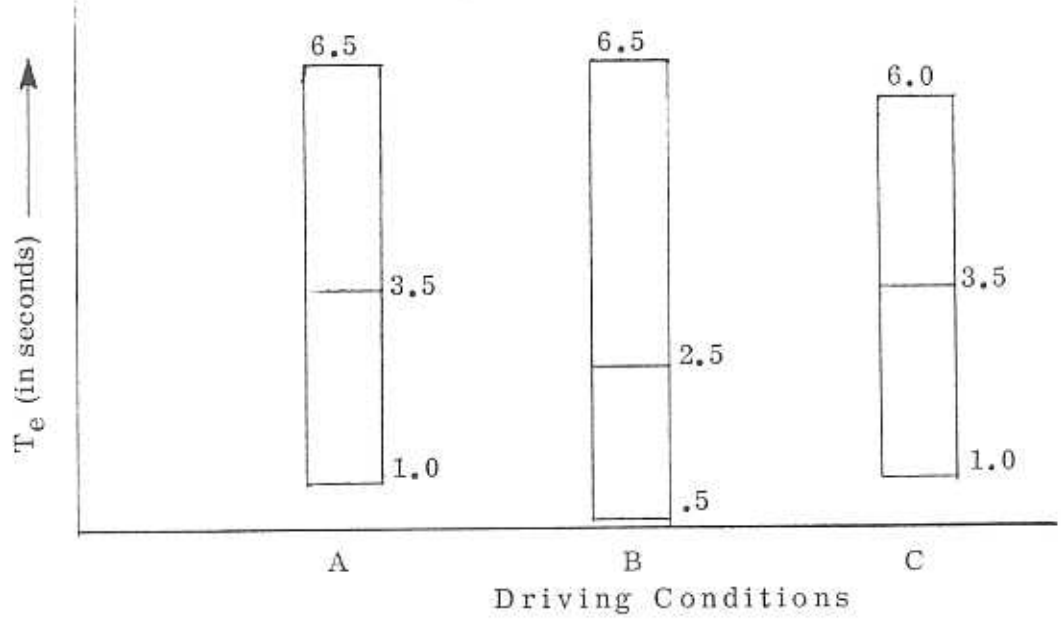


Figure 4.8.--Effect of Driving Conditions on the 15th, 50th, and 85th Percentile Values of T_e

3. Some Effects of Sequential Signing on the Sign Reading Behaviors of Drivers

Figure 4.9 presents the percentage of signs read; i.e., for which $T_{used} > 0$, as a function of the number of the sign in the sequence in a trial in the three types of driving conditions. The number of a sign in the sequence was defined as the serial number of sign location in which the driver encountered a sign (or signs in case of multiple signs at a location) counted from the beginning to the end of a trial. (See Figure 3.4 for illustrative definition of sign location number; i.e., the number of sign, in a sequence of signs.) The data presented in Figure 4.9 is obtained by aggregating the data for all subjects and over all trials in each of the types of driving conditions.

In the driving condition of type A, the sequence of signs in all trials was as follows (see Figure 4.1):

1. sign indicating exit 1 mile ahead,

2. "Gas - Food" sign,

3. sign indicating exit "Next Right", and

4. exit sign.

The percentage of signs read by the drivers in the above type of sequence were 86, 54, 75, and 100, respectively, for each successive sign (see Figure 4.9). This clearly shows that the drivers generally read the majority of first signs in the sequence and then other signs in the sequence were looked at depending upon their importance in relation to the driving task. The curves shown in Figure 4.9 for driving conditions B and C are difficult to interpret on the basis of such aggregated data primarily because the trials in driving conditions B and C required drivers to pass an average of 4 to 6 sign locations before arriving at the instructed exit . (See Figure 4.2 illustrating four sign locations in a trial.) Further, it should be noted that under these driving conditions the number of signs at each location varied from one sign to three signs. However, from the data presented in Figure 4.9 for the conditions B and C, the following suggests two important results.

1. The first signs in a sequence of signs are generally read by the drivers much more than the later signs. Further, it should be noted that the percentage of the signs read and the time spent by the drivers in reading the signs appears to be highly correlated. (See Table 4.2 and compare with data in Figure 4.9.)

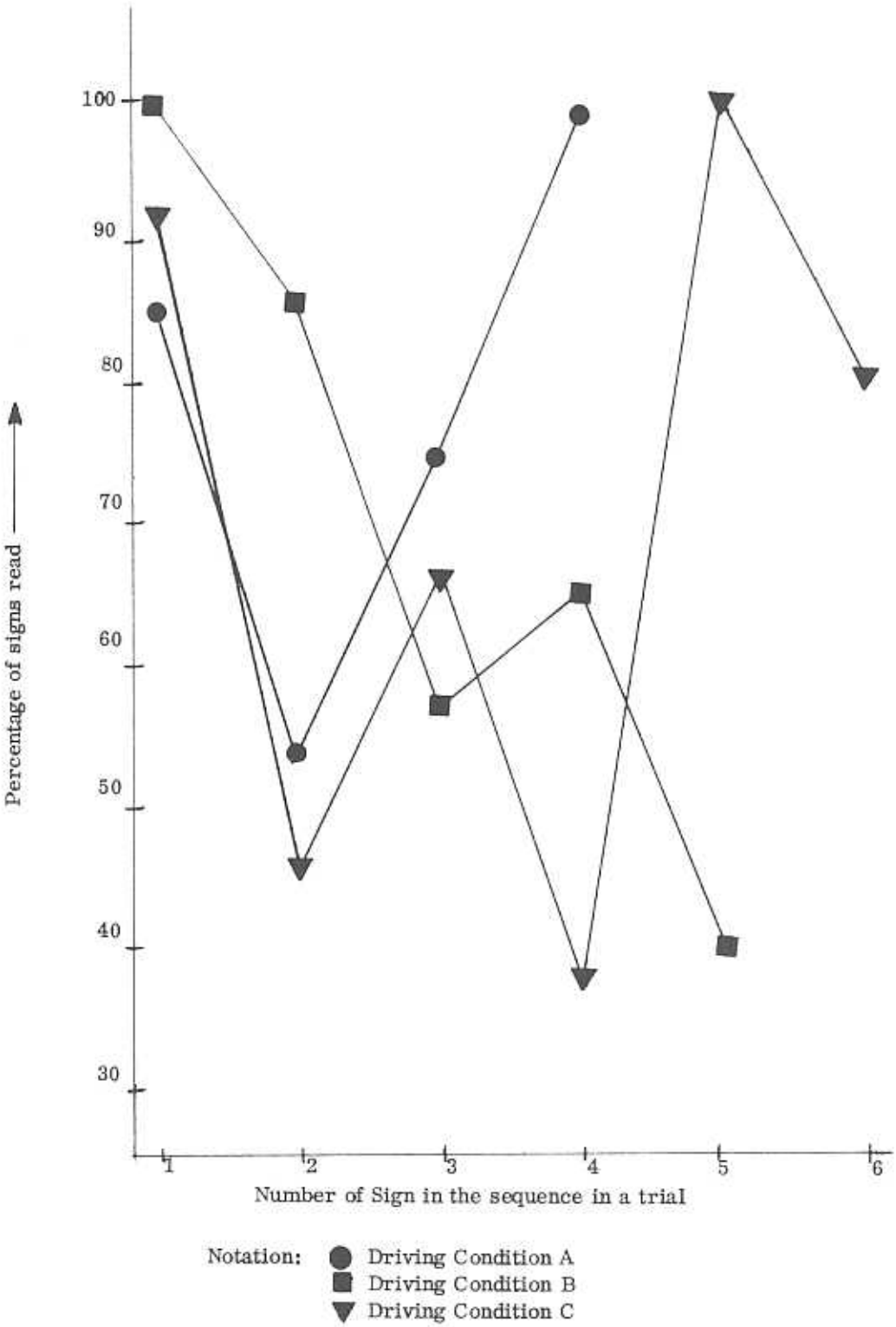


Figure 4.9.--Percentage of Signs Read as a Function of Number of Signs in the Sequence

Table 4.2

Mean Values of T_{used} as a function of Number of Sign in the sequence

Number of Sign in the Sequence	Driving Condition		
	A	B	C
1	2.672	1.165	0.682
2	0.668	1.055	1.351
3	2.176	0.342	0.378
4	1.359	0.698	0.446
5	—	0.233	1.099

2. The subsequent signs are not generally looked at as often (i.e., lesser percentages of the subsequent signs are read) and the time spent on these signs are also lower, except when they require a major control action such as exiting or lane changing (i.e., when the subsequent signs encountered are of type PR). The above statement can be supported on the basis of data presented in Table 4.3.

It should be noted that the above two findings were obtained for the signing sequences in which the messages consistent with the first sign were presented on the subsequent signs. The results, therefore, would not be necessarily true if the subsequent signs do not present messages consistent with the first sign in the sequence.

4. The Effect of Signing Relevancy on Sign Evaluation Measures

Table 4.3 presents the percentages of sign read as a function of the driving conditions and the relevancy of signing with respect to the driving task. From the data presented in this table, the following conclusions can be drawn:

1. As the visual load due to traffic density is increased the percentage of signs read by the drivers decreases.

2. As the visual load (due to traffic density) is increased, drivers tend to disregard signs which are not relevant to their driving task.

3. In general, the drivers sample information from more signs which present them information pertaining to the route (or destination) as compared to the signs which do not present information pertaining to the route.

Table 4.4 presents mean values of the basic measures defining sign reading behaviors of drivers as a function of driving condition and the type of relevancy. On the basis of the data presented in this table, the following conclusions can be drawn:

1. The measure T_f does not seem to be influenced by type of relevancy but is highly affected by driving condition; i.e., visual loading. (From Table 4.4, note that the mean values of T_f are smaller over all three types of relevancy types in conditions B and C as compared to the mean values of T_f for corresponding relevancy types in condition A.)

Table 4.3

Data Illustrating Percentages of Signs Read as a Function of Driving Conditions and the Relevancy of Signs with respect to the Driving Task

Type of Relevancy	Driving Condition		
	A	B	C
NR (Not Relevant)	85.2	73.7	37.5
NP (Not Pertaining to Route)	54.5	62.5	64.3
PR (Pertaining to Route)	80.0	75.0	91.0
All Signs (Aggregated over all types of relevancy)	77.2	70.0	69.9

Table 4.4

Mean Values of Measures Defining Sign Reading Behaviors of Drivers as a Function of Driving Conditions and the Type of Relevancy

Type of Driving Condition	Type of Relevancy	Mean Values in seconds of :				No.* of Signs
		T_{used}	T_e	T_f	T_{max}	
A	NR	1.616	3.26	9.46	13.08	27
	NP	2.162	3.52	10.42	12.04	11
	PR	2.686	6.27	9.77	12.37	10
B	NR	0.910	4.85	7.54	11.54	19
	NP	1.066	2.33	7.30	16.61	8
	PR	0.316	2.68	5.83	16.83	8
C	NR	0.188	4.92	5.56	10.95	8
	NP	0.910	3.44	6.57	13.11	42
	PR	0.873	3.08	7.17	13.56	22

*Note: The sample size included only those signs for which values of T_{used} were non-zero.

2. The drivers generally spend less time looking at the signs which do not give relevant information to perform the driving task; i.e., signs of type NR. This finding can be supported by observing the mean values of T_{used} for relevancy type NR for all the three driving conditions and comparing these values with the mean values of T_{used} for relevancy types NP and PR for the corresponding driving conditions in Table 4.4.

The differences in the mean values of T_{used} between relevancy types NP and PR, presented in Table 4.4 do not appear to show any discernable pattern. However, the differences between the signs of type PR and NP were observed in the driver's time-sharing processes with the signs and other tasks in driving.

Figures 4.10 and 4.11 present data in illustrating the differences in the time-sharing processes of drivers in reading signs that present relevant information in relation to the driving task. From these figures, the following conclusions can be drawn.

1. The signs which provide positive information; i.e., of type PR, require high time-sharing activity. This is illustrated in Figure 4.10, which shows that the 50th percentile values of T_i/T_{used} are smaller for signs of relevancy type PR as compared to signs of relevancy type NP.

2. Figure 4.11 shows that the 50th percentile values of T_i for signs of relevancy type PR are larger than the signs of relevancy type NP.

3. The above two findings when considered concurrently suggest that the signs which present information pertaining to the driving task are very highly time-shared; i.e., they are not only time-shared with higher concentration but also over longer time intervals.

4. Under higher visual loads (due to traffic) the increase in T_i (for signs of relevancy of type PR) is generally achieved by shortening T_e; i.e., T_f appears to be unaffected.

The position of the signs of relevancy type in the sequence of signs is another important variable and even though it is studied in greater depth in the study F-6, some insights can be gained on the sign reading behaviors of drivers from the data obtained in driving condition B and C. Figure 4.12 presents the percentages of signs read as a function of relevancy of sign and the number of sign in the sequence. The data presented in this figure suggests the following.

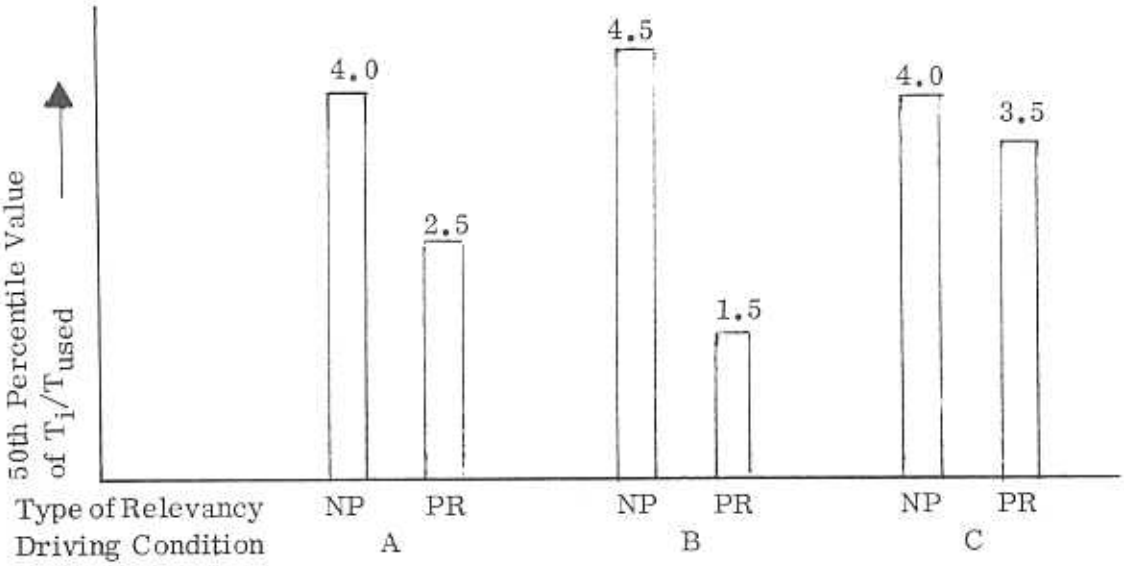


Figure 4.10. --Fiftieth percentile values of T_i/T_{used} as a function of sign relevancy and driving condition

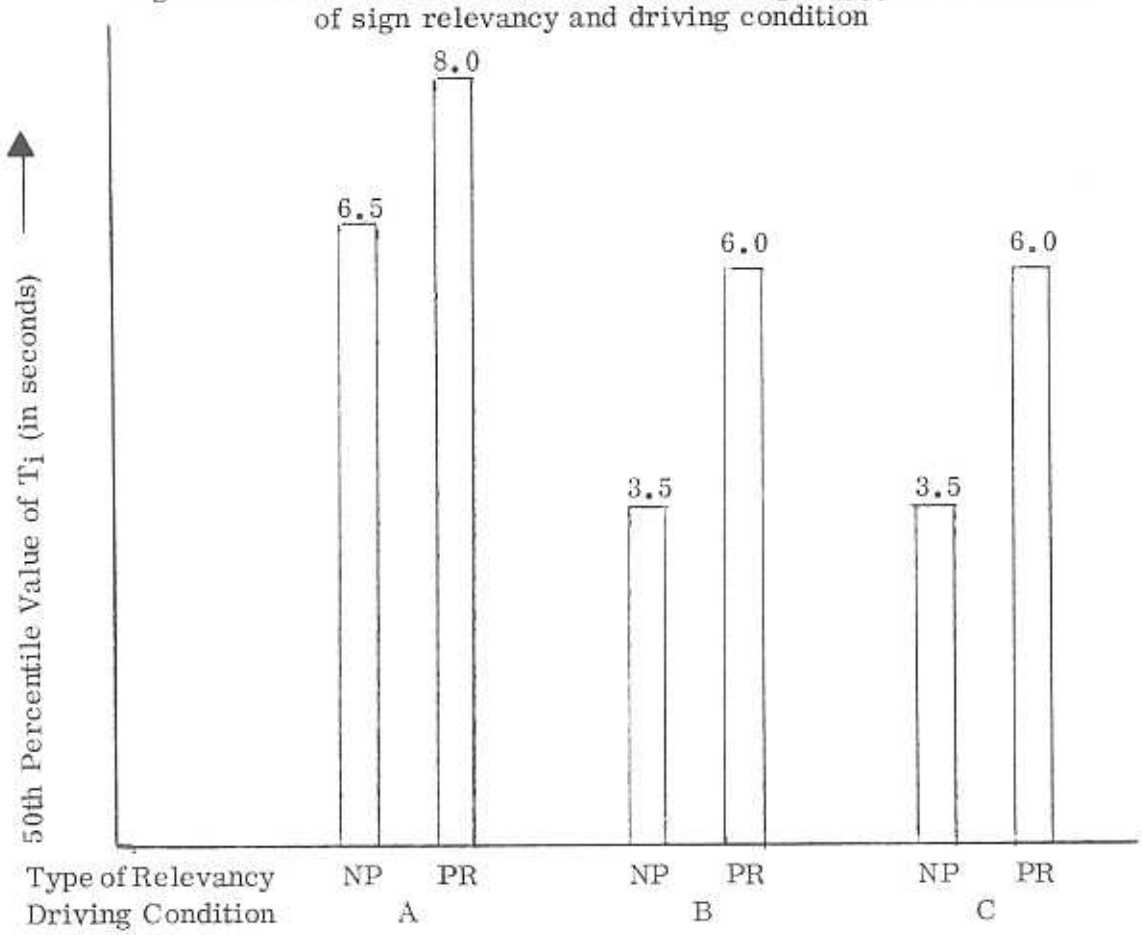
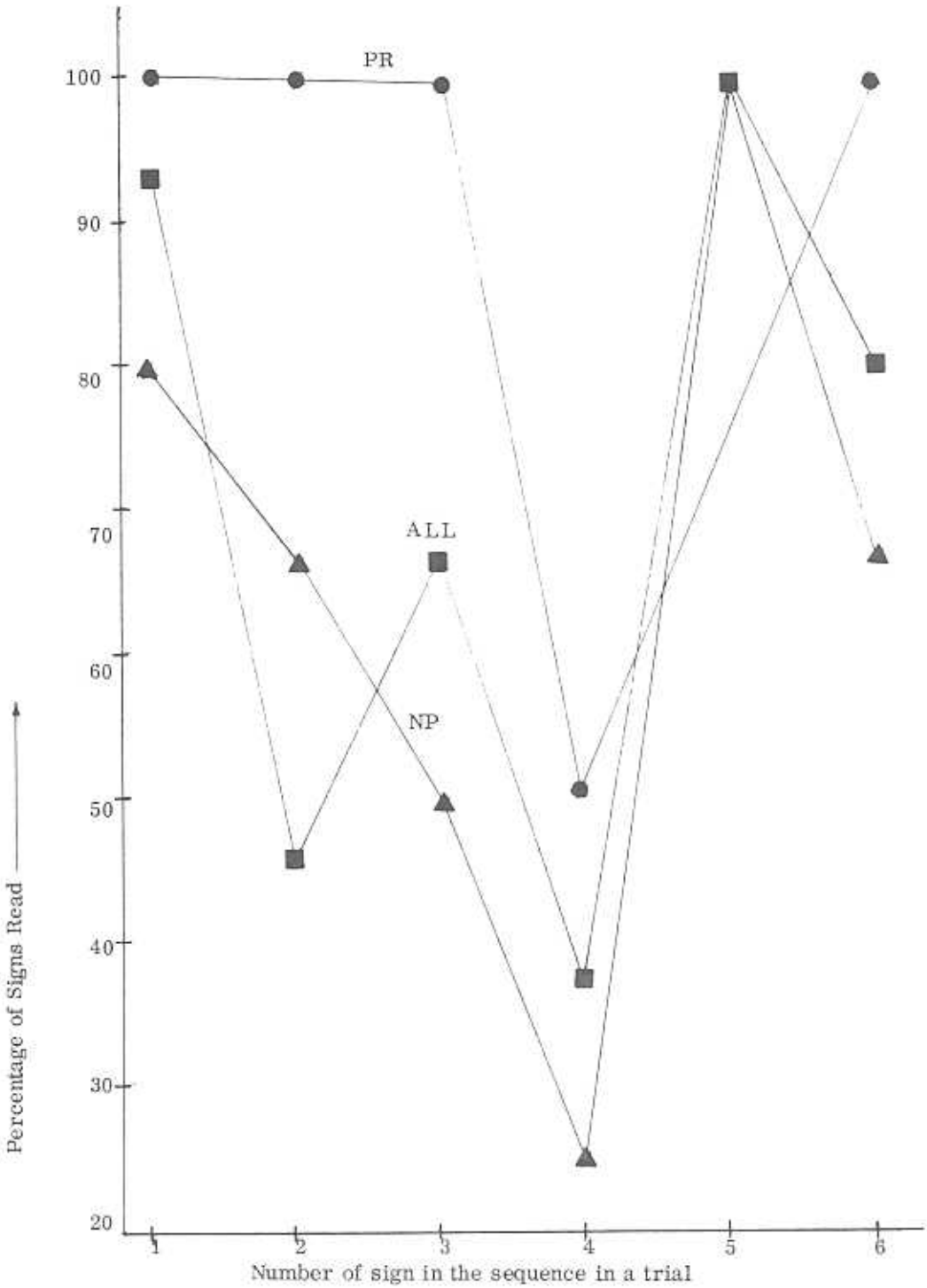


Figure 4.11.--Fiftieth percentile values of T_i as a function of sign relevancy and driving condition



Note: The data presented in this figure is obtained by aggregating data over all subjects and all trials in driving condition C.

Figure 4.12.--Percentage of Signs Read in Driving Condition C as a Function of Relevance of Sign with Respect to the Driving Task and the Number of Signs in the Sequence

1. The emphasis of signs of relevancy type NP, in general, decreases with the number of sign in the sequence as compared to signs of relevancy of type PR.

2. In the test routes used for the condition C, the 5th and 6th signs were generally the last signs that the driver encountered before exiting. The data, therefore, suggests that just prior to the major control action, the importance of signs of both types increases; i.e., the percentages of signs read increases as a sign location approaches a major control action.

Finally, it should be noted that the independent variable "Type of Mounting" could not be investigated on the basis of data in this experiment and this was primarily because of the finding that visual loading affects the sign reading behaviors of drivers much more drastically as compared to the type of mounting, and the two variables; i.e., 1) the visual loading, and 2) the type of mounting were confounded in this study. Therefore, the issue of side-mounted versus overhead-mounted signs was investigated in the study F-4.

Study F-2

Title: A Controlled Validation Study Using Speed Limit Signs

Objective: The primary objective of this study was to determine the maximum sight distances from which a sign could be read under actual driving situations. The sight distances obtained from this study were used for the investigations of the following:

1. to determine the relationship of visual acuity of the test subjects to their maximum sight distances,

2. to test the assumption that the visual angle subtended by the letters should be at least 5.5 times the foveal resolution angle to form a resolvable image of the message displayed by a sign (It should be noted that this assumption was used for the analysis of the driver eye-movement data in the computer program SEADEM I and II.) and,

3. to determine the effect of lateral placement of signs on the sign reading behavior of drivers.

DESCRIPTION OF THE EXPERIMENT

It should be noted that this experiment was described in detail in the interim report of this project; therefore, on the following pages the experiment and the results are described as briefly as possible. An interested reader is, therefore, referred to the interim report of this project for more details.

In this experiment two sets of speed limit signs of the R-10 type were used. These speed limit signs were specially designed by the Ohio Department of Highways. The first set of signs were of size 24" x 30" and the speed limit numbers on these signs were 10" high and of type D. The second set of signs were of size 48" x 60" and the speed limit numbers were displayed on these signs in 16" high D type letters. Both the sets consist of the following four speed limits: 20, 30, 50, and 60 mph.

These signs were erected on a newly built section of I-70 before it was open for traffic. The drivers in this experiment were asked to drive in a specified lane and to change the speed of the vehicle to the speed displayed by the speed limit signs as soon as they were able to read the numbers on the signs. Four subjects were used in this experiment and they were asked to drive on a test route four times. Along the test route, four speed limit signs were erected, and after each trial the signs were changed in order to remove any effect due to the familiarity with a sign at a given sign location. The subjects drove in different lanes and thus the effect of lateral distances of the speed limit signs on the maximum sight distances could be evaluated.

During this experiment the eye movements of the drivers were obtained. The eye-movement data were synchronized with an oscillograph recorder on which velocity of the vehicle and gas and brake pedal deflections were recorded. In order to determine the exact instant at which a driver passed a speed limit sign, the experimenter pushed a button when passing each sign which caused a step change on a separate trace on the oscillograph paper.

Results

The maximum sight distances required for the analyses were obtained by observing the gas and brake pedal deflections made by the driver as he approached the speed limit signs. The driver eye-movement data was primarily obtained to verify if the drivers were constantly staring at the sign until the specified speed limit number was perceived. From the data, the visual angles subtended by the speed limit numbers at the time the driver made a control response; i.e., released the gas pedal when the displayed speed limit was smaller than the speed prior to approaching the signs, or pushing the gas pedal down when the displayed speed limit was greater than the speed prior to approaching the sign, were obtained.

The results obtained from this study were as follows.

1. The visual angles subtended by the speed limit numbers at the sight distances at which the subjects initiated the gas pedal response, in all the trials, ranged between 4.9 to 5.7 times the foveal resolution angle of the test subjects. This finding, thus, supports the assumption that about 5.5 times the resolution angle is necessary to resolve the message displayed by a sign.

2. It was found that with increase in the lateral distances of signs (from the path of the vehicle) the horizontal distances available for reading the signs decrease. The relationship between a decrease in longitudinal distances with an increase in lateral position obtained in this experiment was found to be comparable to the relationship that one would have obtained by considering the geometric configuration and the visual acuity obtained under static situations.

3. Perhaps the most important implication of the above findings is that visual acuities obtained under static conditions can be related to sign reading under dynamic visual environments in driving situations with fairly good accuracy.

Study F-3

Title: An Exploratory Study for the Investigation of the Possibility of Sign Reading by the Extra-Foveal Vision

Objective: As mentioned earlier, during the preliminary analysis of the data collected in the study F-1, it was observed that the drivers could read the signs by their extra-foveal vision. The determination of the measures T_e, T_f, T_{used} (see Chapter II) was, therefore, also based on the consideration of the resolvability of the message on the sign in the extra-foveal portion of the drivers visual field. Since in the literature there is considerable controversy in understanding the role of extra-foveal vision in sign reading and also the fact that no studies in this regard have been found in the literature that are conducted under actual driving situations, it was decided to conduct an exploratory study. There is no doubt that more research is required to understand the role of extra-foveal vision in sign reading.

DESCRIPTION OF THE EXPERIMENT

This experiment was conducted on a newly built southwest section of the Columbus Outerbelt (I-270). This section consists of overhead-mounted signs, and it has four lanes (2 lanes in either direction). Two subjects were used in this experiment, namely subject KR and RH. Each subject drove past ten selected overhead signs on the test section.

During each of the trials, the subject was asked to drive behind a lead car and was asked to maintain a constant headway of 100 feet. In all the trials, the lead car was driven at 40 mph. The headway between the two cars was

monitored by using a device called "yo-yo." The description of the "yo-yo" device can be found in Rockwell and Snider (1970). During the trials the subject was asked to constantly stare at a target placed on the lead car. (See Figure 4.13.) The target was mounted at a height of 4.97 feet from the surface of the road. Thus, when the subject drove behind the lead car at exactly 100 feet and stared at the target, his visual axes were located at 1^{o} above the horizontal plane (parallel to the surface of the road) and passing through his cyclopean eye position. The seat of the subject car was so adjusted that the eye height of both the drivers was approximately 3.5 feet from the surface of the road.

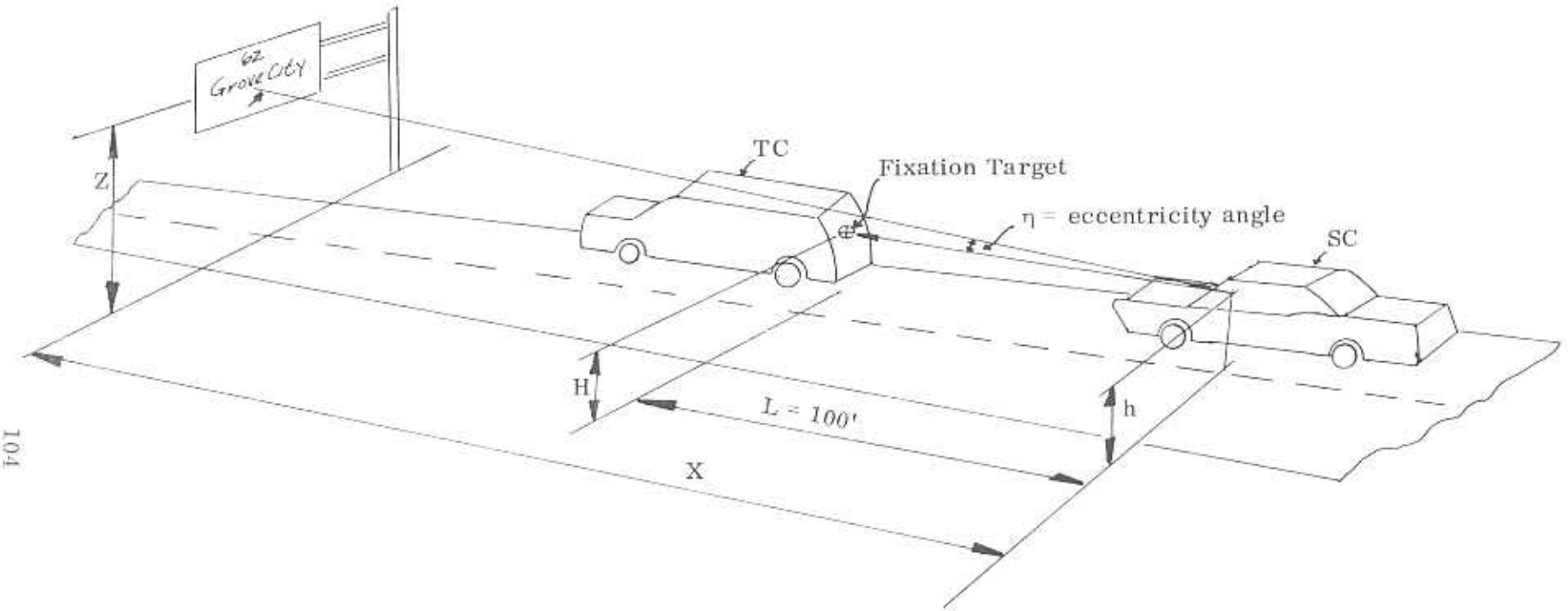
In addition to the task of headway maintenance and the task of staring at the target, the subject was instructed to read the overhead signs and to report the perceived message on the sign. It should be noted that it was emphasized that under no circumstances the subject was to move his eyes from the target. Since it was necessary to keep the headway between the cars as close to 100 feet, the experimenter constantly monitored the headway on a display mounted in the subject car and provided the subject feedback when the headway was outside $\pm$ 10 feet headway bandwidth.

Table 4.5 shows that under the above described geometric configuration the message displayed on the sign in 16" high letters could be resolvable to the subject in the extra-foveal portions of his visual field. It should be noted that foveal vision approximately occupies a circular field of 0.9^{o} radius around the visual axis. The values of the angles γ and α (η) presented in Table 4.5 are computed in the same manner as described in Chapter II. It should also be noted that in developing the methodology (Chapter II) it is assumed that the letters on the sign could be only resolvable if they subtend angles greater than or equal to 5.5 times the resolution angle on the part of the retina where the image of the letters falls. Table 4.5, thus, shows that under the geometric configuration used in this experiment the image of the standard 16 inch high capital letters on the sign could be read only by the extra-foveal vision when the driver is within 300 feet of the sign.

During all the trials of this experiment the eye movements of the drivers and the headway data were recorded. The collected eye-movement data was later observed to check if the subject performed the task of staring at the target while approaching a sign. The headway data was used to check the headways while approaching a sign.

Results

The verbal responses made by the subjects were recorded by the experimenter. In all the trials of the two subjects in which the headways and the visual axes of the subjects were at the required experimental levels (or positions), it was found that the subject could usually read part of the message presented in 16" high letters.



Note: h = eye height of the driver from the surface of the road
H = height of the target on the target car from the surface of the road
Z = height of the mid-point of the overhead sign = 20 feet
X = longitudinal distance between the sign and the cyclopean eye position of the test driver

Figure 4.13.--Sketch Showing the Geometric Configuration between the Subject Car (SC), the Target Car (TC), and the Overhead Mounted Sign on the Highway

Table 4.5

Illustration of the Analytic Determination of the Possibility of Sign Reading by the Extra-foveal Vision as Considered in the Developed Methodology

Longitudinal distance of the driver from the sign = x in feet	Angular location of the sign = θ $\theta = \tan^{-1}\left\{\frac{Z-h}{x}\right\}$ Note: Z = 20 feet	Eccentricity angle = η (assuming the subject staring at $(0^o, 1^o)$)	Visual angle subtended by the 16' high letters on the sign = γ in minutes of arc	$\frac{\gamma}{5.5}$ (in minutes of arc)	Resolution angle $\alpha(\eta)$ in minutes of arc	Can the letters be read? Yes, if $\frac{\gamma}{5.5} > \alpha(\eta)$
50	18^o 15'	17^o 15'	87	15.80	8.50	YES
100	9^o 22'	8^o 22'	45	8.18	5.40	YES
200	4^o 42'	3^o 42'	23	4.18	3.05	YES
300	3^o 9'	2^o 9'	15	2.72	2.55	YES
400	2^o 21'	1^o 21'	12	2.18	1.90	NO
500	1^o 55'	55'	9	1.63	1.52	NO
600	1^o 33'	33'	8	1.45	1.20	NO
700	1^o 19'	19'	6.7	1.21	1.00	NO
800	1^o 11'	11'	5.7	1.03	0.86	NO
900	1^o 2'	2'	5.0	0.91	0.71	NO
1000	55'	-5'	4.7	0.85	0.80	NO
1100	51'	-9'	4.0	0.72	0.84	NO
1200	47'	-13'	3.8	0.69	0.90	NO

Table 4.6

Illustration of the Results Obtained from the Study F-3

Sign Number	The Message on the Sign The underlined letters (or words) were perceived by the subject under the experimental trial.
1	71 Columbus Cincinnati Jct 1 MILE
2	62 Grove City
3	Georgesville Road EXIT 1 MILE
4	Georgesville Road RIGHT LANE
5	Roberts Road EXIT 3/4 MILE
6	Roberts Road

Table 4.6 presents some illustrations of the results obtained from subject KR's data. From the data presented in the Table 4.6, it is obvious to note that if the message displayed on the sign was familiar to the driver, he could easily read it, in spite of the blurred image of the message on the driver's retina. Forbes (1969) also reports the similar findings that the familiar messages on the signs can be read from higher sight distances as compared to the unfamiliar messages.

The results of this experiment, thus, in general, support that road signs can be read by the drivers in their extra-foveal vision.

Study F-4

Title: A Study for the Evaluation of Sign Changes on I-90 in Cleveland

Objective: The primary objective of this study was to apply the developed methodology to evaluate the sign changes made by the Ohio Department of Highways on the Memorial Shoreway (I-90) in Cleveland. In this study the signing on an eight mile section of I-90 between Liberty Boulevard and Babbitt Road was studied. Around the middle of 1970, the Ohio Department of Highways replaced old signing on the above mentioned section of I-90 with new improved signing.

Research Approach

The approach taken for evaluation of sign changes was to collect driver eye movement and driver-performance data on this section of road under identical conditions (i.e., using same subject, under identical subject instruction, and under similar traffic conditions) both before and after the sign changes were made. The data obtained in the above two sets of runs; i.e., before and after the sign changes were made, was then analyzed by using the computer program SEADEM I and the sign evaluation measures were compared to evaluate the sign changes.

Design Differences Between Old and New Signs

Table 4.7 presents a summary of design differences between the old and new signing on the section of I-90 used for this study. For more detailed description of the sign changes an interested reader is referred to the plans (Cuyahoga County, CUY-90-20.72) prepared by the Ohio Department of Highways.

Table 4.7

Differences in Physical Characteristics of Old and New Signs

Characteristics	Old Signs	New Signs
Type of Mounting	Side Mounted	Overhead
Number of Signs Per Location	One	One to Three
Number of Signs Per Exit	Two to Three	Four
Length of Message on a Sign:	1-4 lines (59% signs with one line message)	2-3 lines
Number of Lines:		
mean	1.41	2.40
std. dev.	0.79	0.66
Number of Words:		
mean	3.33	5.45
std. dev.	2.23	2.04
Number of Letters and Numbers:		
mean	9.60	19.35
std. dev.	6.92	7.05
Sizes of Letters and Numbers on Signs	16", 12", 10", 5", 4", (majority of signs had 12" capital letters)	16", 15", 12", 10" (standard)
Approximate Average Area of a Sign	30 sq. ft.	110 sq. ft.
Total Number of Longitudinal Locations of Signs on the Six Test Routes	22	37
Total Number of Signs on the Six Test Routes	22	57

DESCRIPTION OF THE EXPERIMENT

Five college age male subjects with normal vision participated as test drivers in this study. All the five drivers were so selected that they were unfamiliar with the Cleveland area. The data for the test subjects was collected under the two types of signing conditions; i.e., 1) prior to sign changes and 2) after the sign changes. Each subject, thus, was taken two times to Cleveland for data collection and these two trips for each subject were made at an interval of about six months. The data under the conditions of old signing was collected between January, 1969 to May, 1970, and the data under the new signing conditions was collected between September, 1970 to January, 1971. Due to very heavy traffic on weekdays on I-90, all data for this study was conducted on Sunday mornings.

Each subject under each type of signing condition had to make two consecutive runs on the selected test route on I-90. Each run consisted of the following six trials. (See Figure 4.14.)

Trial 1:	Entering I-90 eastbound at Liberty Blvd. and exiting at Eddy Road.
Trial 2:	Entering I-90 eastbound at Eddy Road and continuing on I-90 until further instructions.
Trial 3:	After passing the exit of E. 140th Street while traveling eastbound, the subjects were instructed to exit at Babbitt Road.
Trial 4:	Entering I-90 westbound at Babbitt Road and continuing on I-90 until further instructions.
Trial 5:	After passing the exit of E. 185th Street while traveling westbound the subjects were instructed to exit at E. 152nd Street.
Trial 6:	Entering I-90 westbound at E. 152nd Street and exiting at Liberty Blvd.

(Note: The signs encountered by the drivers while driving on the test sections defined by the six trials are presented in Appendix A.)

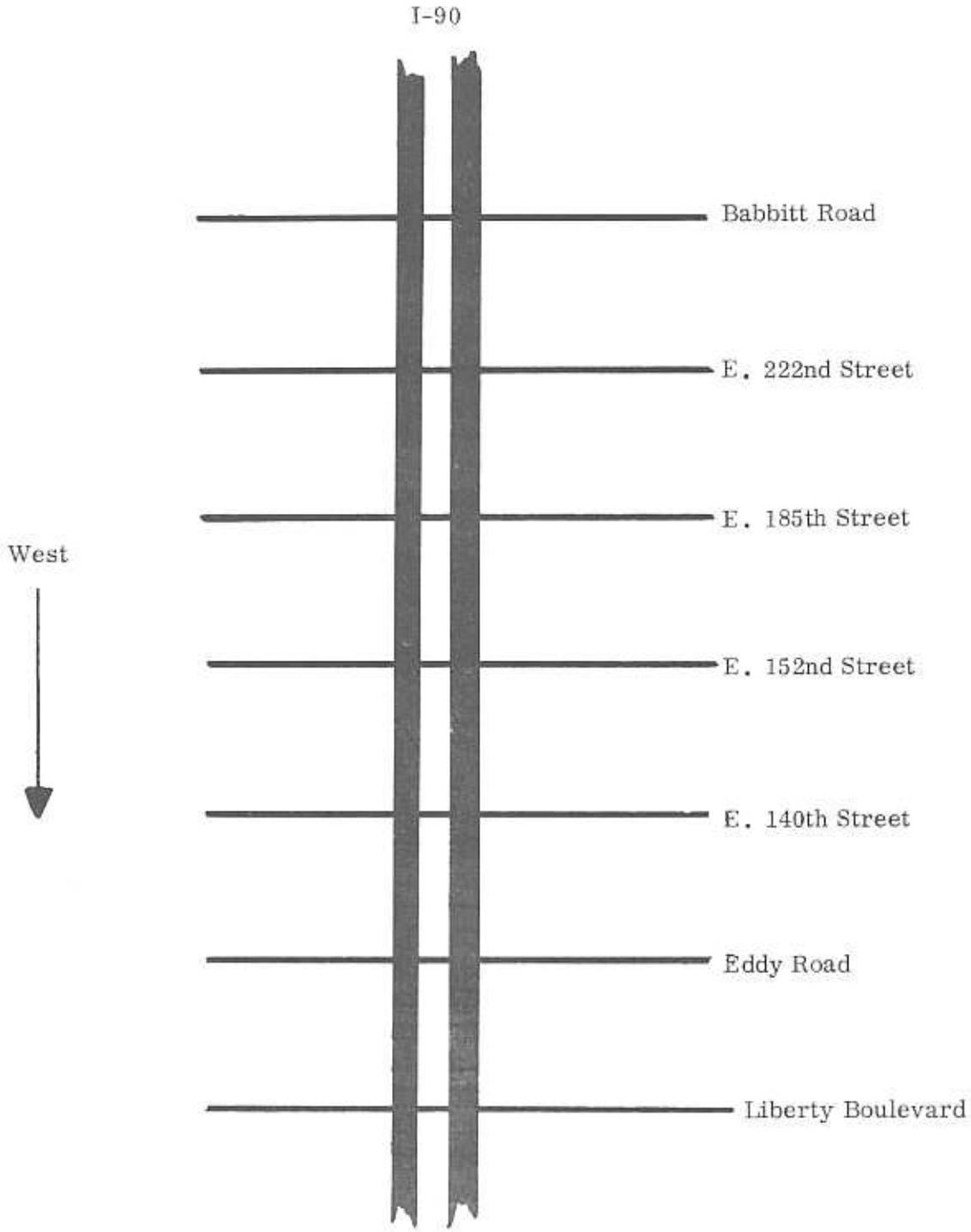


Figure 4.14. --Section of Memorial Shoreway (I-90) Studied in Study F-4.

A run, thus, included the above six trials and it essentially covered the entire section between Liberty Blvd. and Babbitt Road in both directions. At the beginning of each trial in each of the runs, the subjects were given instructions. The instructions only included information about the test route; i.e., the subjects were either told where to enter and where to exit or they were simply asked to continue driving until further instructions. It should be noted that all the subjects used in this experiment were unaware of the true objective of this study; i.e., the subjects were told that it was a study to determine how the vehicle handles on the test section of the highway, the the word "sign" was not mentioned to them in any of the instructions. For more detailed descriptions of the testing procedure, subject instructions, and the details of the signs, an interested reader is referred to the interim report of this project (Rockwell, et al., 1970).

The subject instructions for the six trials in a run were different. The instructions for the trials 1, 3, 5, and 6 required the drivers to exit, whereas, in trials 2 and 4, the subject instructions did not include exiting instructions; i.e., they were merely asked to continue driving on the highway. Therefore, the signs encountered by the drivers in each trial had different relevancy; i.e., relevancy of sign in relation to the driver's informational need. The signs therefore, could be classified into three mutually exclusive types of relevancy, namely, 1) the signs that were not relevant (NR) to perform the instructed driving task, 2) the signs that did not present information pertaining to the route (NP), and 3) the signs that presented information pertaining to the route (PR).

Table 4.8 shows the combination of independent variables into which the data obtained in this experiment can be subdivided for the purposes of analysis.

Results

The data obtained for each of the trials conducted for all the five subjects in this experiment was processed by using the computer program SEADEM I. The output of the program SEADEM I consisted of the sign evaluation measures and ratios for every individual sign in each of the trials.

At the time when the interim report on this project was written, the results presented on this study were based on the analysis of the sign evaluation measures obtained for only two subjects. After the preparation of the interim report, the data for the three remaining subjects was analyzed. The results presented here are based on the complete data obtained from this study. However, while presenting the results in this report, an attempt is made to avoid repetition of the results and the data which were described in the interim report. An interested reader is, therefore, suggested to refer to the interim report for a more complete understanding of the results and their implications.

Table 4.8

Matrix Depicting Combination of Independent Variables Considered for Study F-4

		Signing Condition			
		Old Signs (Before Sign Changes)		New Signs (After Sign Changes)	
Level of familiarity		F1	F2	F1	F2
Type of Relevancy	NR				
	NP				
	PR				

Note:
- F1= no familiarity (represents the situation of unfamiliar driver)
- F2= low familiarity (represents the situation of an unfamiliar driver driving second time on the test route)
- NR= signs that are "Not Relevant;" i.e., the driver does not need information from the sign to continue on the highway
- NP= Not Pertaining to route; i.e., the signs that do not present information pertaining to route or destination
- PR= Pertaining to Route; i.e., the signs that present relevant information pertaining to route or destination

The results discussed in the following pages are presented at three levels of increasing sophistication. Each successive level of the presentation of results is so considered that it allows the investigation of the effect of increasing number of independent variables and their combinations in a systematic manner. The purpose of the analyses in the three levels is as follows:

Level 1:	to determine important differences between old and new signing by aggregating data for all subjects over all trials and all the signs in each trial,
Level 2:	to determine the effect of the type of relevancy of signing for old and new signs by aggregating data over all trials and all subjects, and
Level 3:	to determine the effects of driver familiarity and the length of message on a sign as a function of signing relevancy, and the signing condition; i.e., old and new.

Further, while presenting the results the following two aims were considered:

1. to present results that would provide more understanding into the sign reading behaviors of drivers, and subsequently contribute towards the enrichment of the methodology, and

2. to present the observed differences in sign evaluation measures and ratios as a function of the characteristics of old and new signing.

1. Results of Level 1 Analysis

1.1 Contributions Towards Understanding Sign Reading Behaviors of Drivers

In order to gain understanding into the sign reading behaviors of drivers two separate correlation matrices were evaluated by considering the basic sign evaluation measures; i.e., T_{max}, T_{used}, T_f, and T_e, by aggregating the data over all trials and all subjects for the old and new signs. The only measures that were significantly correlated were found to be T_{max}, T_{used}, and T_f. The correlation coefficients are presented in Table 4.9. The results obtained here were similar to these obtained in study F-1 and they are as follows:

Table 4.9

Correlation Coefficients Obtained by Aggregating Data for All Subjects over All Old and New Signs on I-90

Signing Condition	Measures Correlated		
	T_{max} and T_f	T_f and T_{used}	T_{max} and T_{used}
Old Signs	0.552***	0.186*	0.064
New Signs	0.642***	0.415***	0.197***

Note: 1. The sample sizes used for obtaining the above correlation coefficients varied between 82 to 304.

2. Hypothesis tested: (Note: ρ = correlation coefficient)

H_0: $\rho > 0$ vs. H_1: $\rho \leq 0$

* = $\rho < 0.10$

*** = $\rho < 0.01$

1. T_f is significantly and positively correlated with T_{max}, and

2. T_{used} is significantly and positively correlated with T_f.

The above results, thus, support the previous finding (from study F-1) that the sign reading behaviors of drivers are heavily influenced upon T_f. The results show that the measure T_f (i.e., the time-distance of the driver from the sign at which the driver begins to acquire information from a sign) is related to T_{max}, which in turn is derived from the following four factors:

1. maximum letter size on the sign,

2. location of sign with respect to the driver,

3. velocity of the driver, and

4. visual acuity of the driver.

The above results, therefore, strongly suggest that as a driver approaches a sign, the time-distance from which the driver begins to acquire information from the sign depends upon the detection characteristics of the sign (which is no doubt a function of the variables 2, 3, and 4) and also on his understanding (after the detection) about the size of the maximum letter size (from the unresolved image of the letters on the sign just after detection).

Further, in the study F-1, it was found that T_f and T_{used} were significantly and positively correlated. The correlation coefficients presented in Table 4.9 suggest that for the new signs the measures T_f and T_{used} were significantly and positively correlated, however, for the old signs the correlation between T_f and T_{used} was low and also significant at low confidence level. Somewhat similar results were also obtained for correlation between T_{max} and T_{used} for the old and new signs. (See the last column in Table 4.9.)

These differences in the significance of the correlation between T_f and T_{used}, and T_{max} and T_{used}, thus, indicate differences in the sign reading behaviors of drivers due to the differences in the old and new signing.

1.2 Indications of Differences in Sign Reading Behavior of Drivers as a Function of Signing Differences

Figure 4.15 presents the 15th, 50th, and 85th percentile values of the measures T_e, T_f, and T_{max}. From the figure, it is obvious that these differences in the correlations discussed above must have been primarily because of higher values of T_{max} for new signs as compared to the old signs.

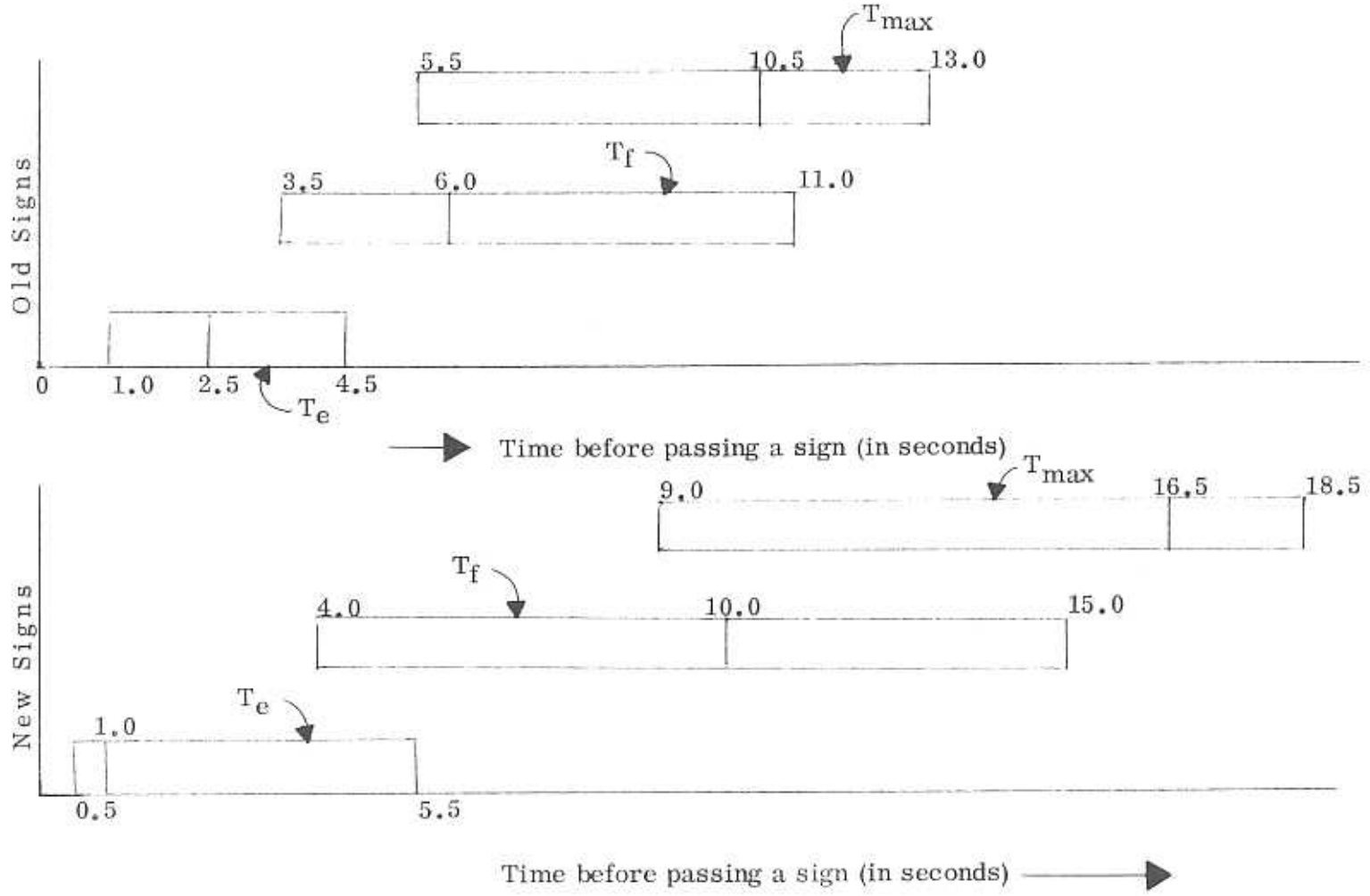


Figure 4.15. --Fifteen, fiftieth and eighty-fifth percentile values of T_e, T_f and T_{max} for old and new signs on I-90

1.3 Increase in the Perceptual Time Shared with New Signs

Figure 4.16 shows that T_i for the new signs was much higher as compared to the old signs and this increase was due to the two following reasons:

1. values of T_f were higher for the new signs as compared to the old signs (see Figure 4.15), and

2. values of T_e were shorter for the new signs as compared to the old signs (see 15th and 50th percentile values of T_e in Figure 4.16). This appears to be primarily due to the differences in the type of mounting of the signs. The overhead mounting characteristics of the new signs thus appear to be responsible for the reduction in T_e.

1.4 Reduction in Driver Urgency and Visual Loading due to New Signs

Observing the data presented in Figures 4.17, 4.18, and 4.19, the following conclusions can be drawn.

1. The 85th percentile value of T_{max}/T_f for new and old signs were respectively, 9.0 and 2.0 (see Figure 4.18). This suggests that if the ratio T_{max}/T_f is considered as a measure for the driver's urgency for acquiring information from a sign, then new signs can be considered to decrease drivers urgency as compared to the old signs.

2. For new signs the values of T_i/T_{used} were higher in spite of increase in T_{used} for new signs as compared to the old signs. In other words, the increase in T_i was much higher as compared to increase in T_{used} for the new signs. This suggests that the time sharing activity of the drivers under new signig was relaxed or was less concentrated (or less loaded). The new signs thus show a definite tendency in unburdening the drivers; i.e., the drivers under the new signs do not appear to be pressed for time to obtain information from the signs as compared to the old signs.

1.5 Increased Detectability of New Signs

Figure 4.20 presents percentage of signs that presented resolvable information to the drivers (i.e., the signs for which $T_{used} > 0$).

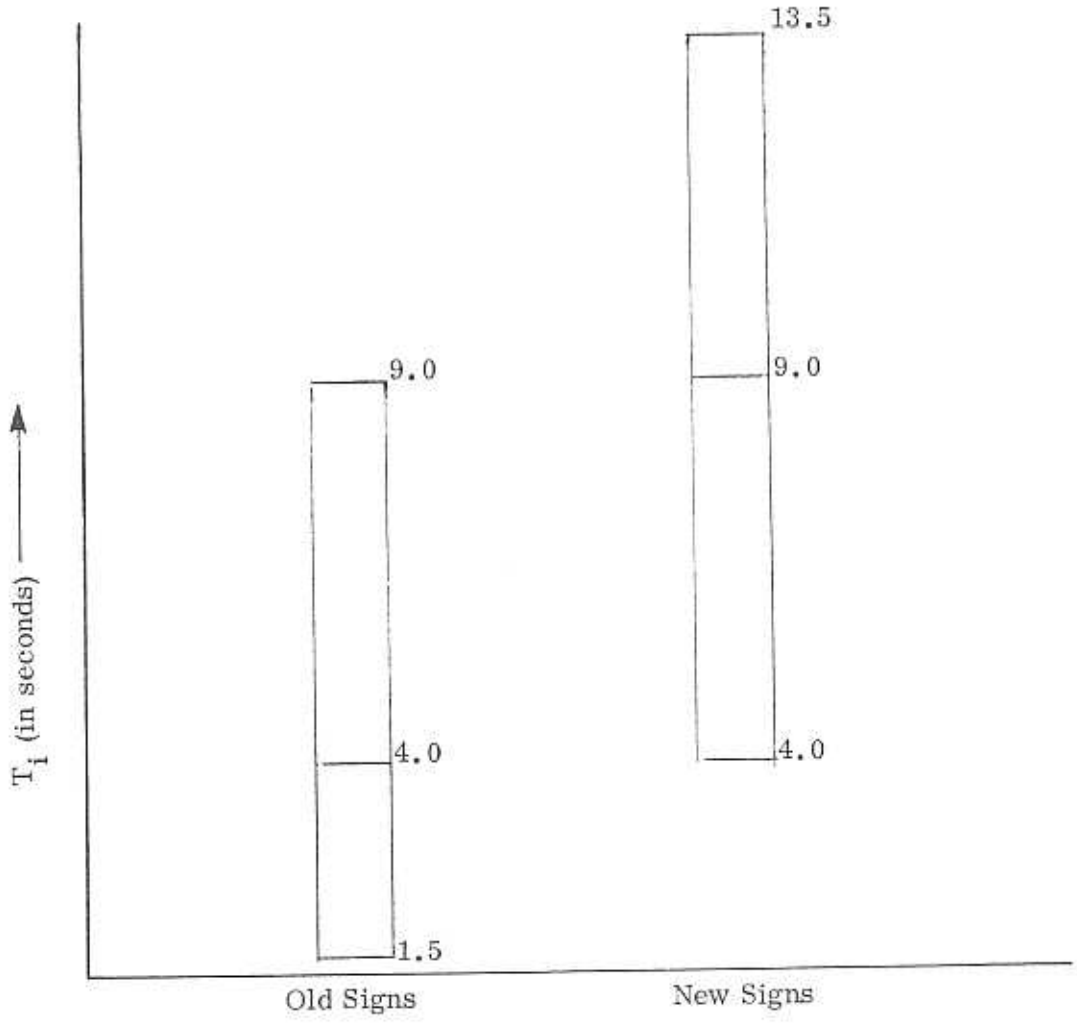


Figure 4.16.--Fifteen, Fiftieth, and Eighty-Fifth Percentile Values of T_i for Old and New Signs on I-90

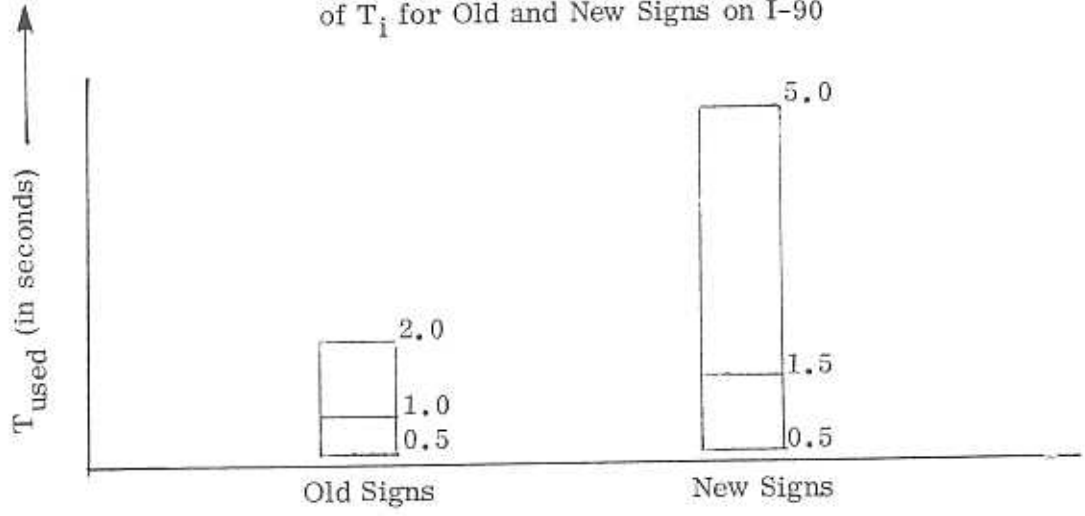


Figure 4.17.--Fifteen, Fiftieth, and Eighty-Fifth Percentile Values of T_{used} for Old and New Signs on I-90

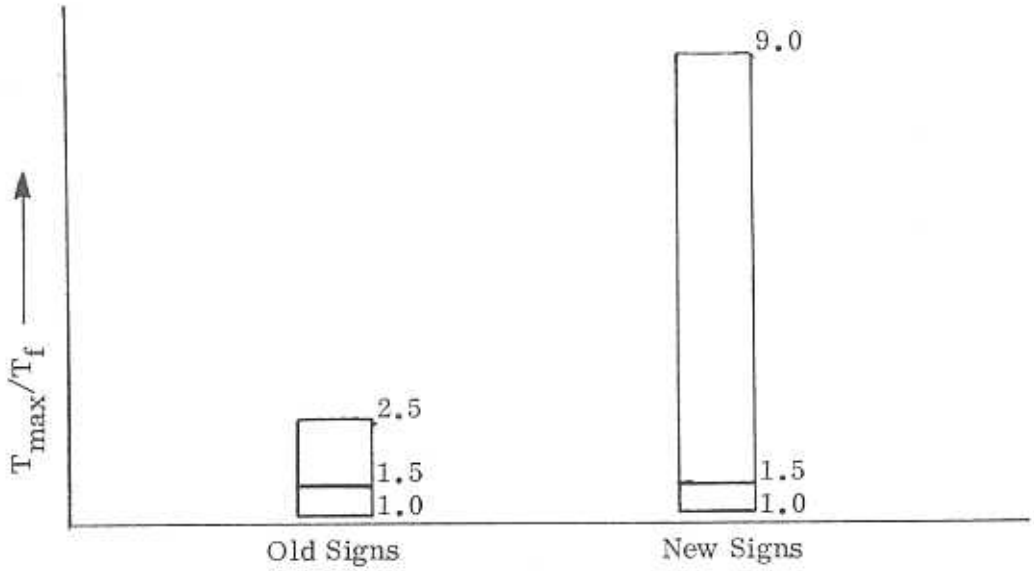


Figure 4.18.--Fifteen, Fiftieth, and Eighty-Fifth Percentile Values of T_{max}/T_f for Old and New Signs on I-90

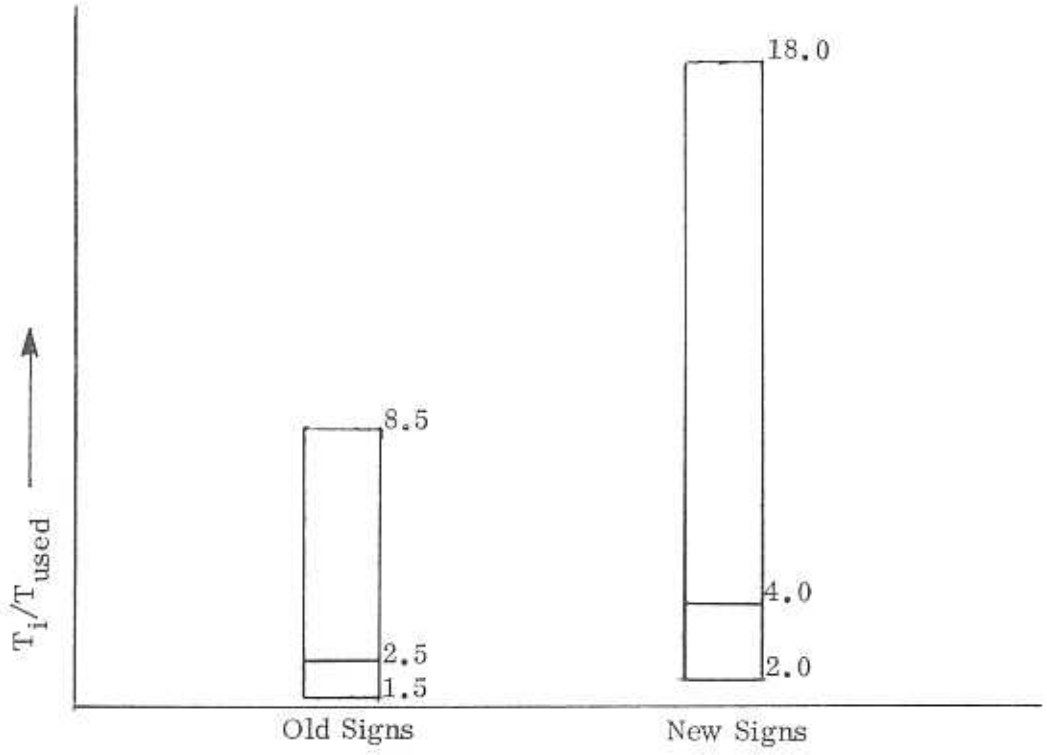


Figure 4.19.--Fifteen, Fiftieth, and Eighty-Fifth Percentile Values of T_i/T_{used} for Old and New Signs on I-90

Considering the overall percentages of signs read by the drivers while driving under old and new signing conditions, it is clear that the drivers read 6.8 percent more signs (i.e., 82.7 - 75.9 = 6.8) after the sign changes. This suggests that the new signs were easy to detect as compared to the old signs.

2. The Results of the Level 2 Analyses

2.1 The Effect of Type of Signing Relevancy

For the analysis of Level 2, the data obtained for the old and new signing was further categorized according to the type of relevancy of the information displayed by the signs with respect to the subject instructions.

Figure 4.20 presents data on the percentage of signs of each of the three relevancy types which provided information to the drivers (i.e., the percentage of signs for which $T_{used} > 0$). Figures 4.21 and 4.22 present mean values of T_{used} for the three levels of signing relevancy for the old and new signs, respectively. It should be noted that the means of T_{used}, presented in the above two figures, were computed by considering the signs for which T_{used} was greater than zero. From the above mentioned three figures the following conclusions can be drawn.

1. All the signs are not attended by the drivers with equal emphasis. The signs which provide information pertaining to the driver's intended destination or route are attended more than signs which do not give information pertaining to the route. Further, the signs which do not give any relevant information to the drivers are read with the lowest emphasis.

2. The percentages of signs read for all the three relevancy types were higher for the new signs as compared to the old signs. This shows that the new signs were easily detectable.

3. T_{used} is a function of relevancy of sign to the driver.

4. The mean values of T_{used} obtained for each of the relevancy types for the new signs were higher as compared to the old signs of the corresponding relevancy type.

2.2 Differences in Correlations Between T_{max}, T_f, and T_{used} as a Function of the Signing Relevancy

Table 4.10 presents the correlation coefficients between the three basic measures: 1) T_{max}, 2) T_{used}, and 3) T_f, for each of the types of relevancy for both the old and new signs.

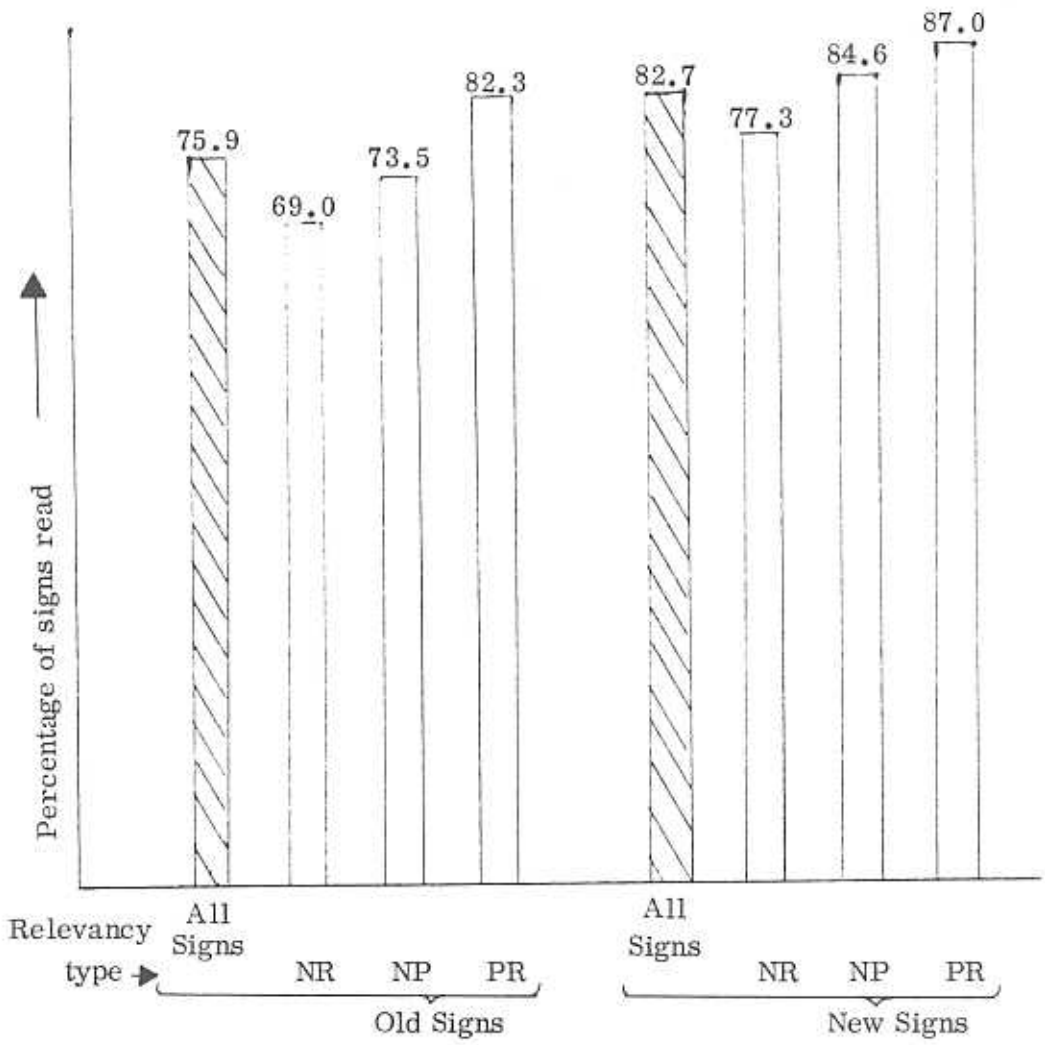


Figure 4.20.--Percentage of Signs Read as a Function of the Relevancy of Signing to the Driving Task for Old and New Signs on I-90

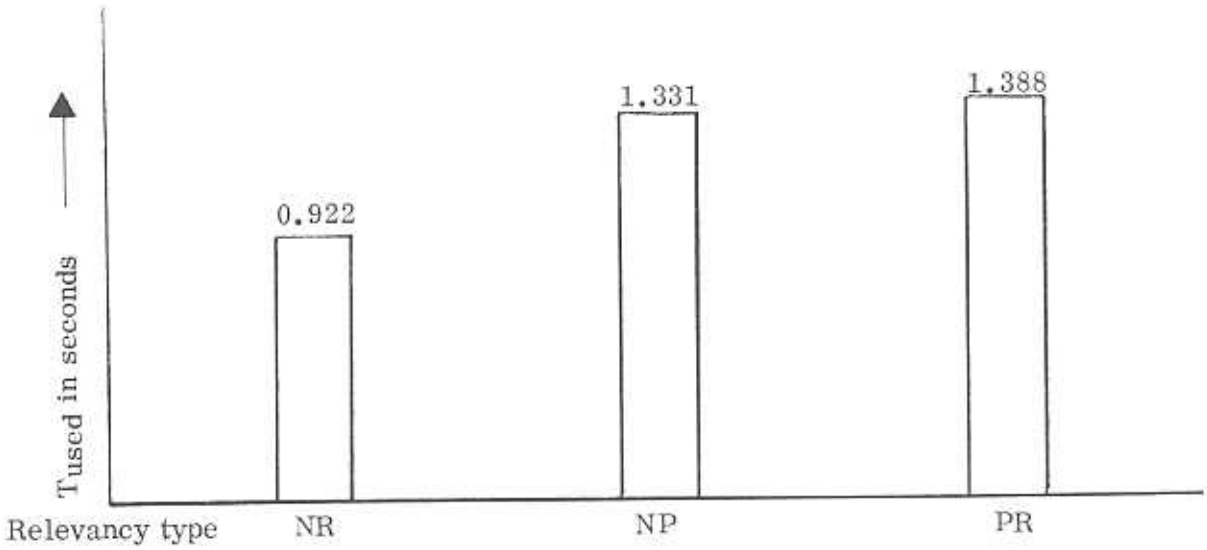


Figure 4.21. --Mean values of T_{used} for the three levels of signing relevancy for old signs on I-90

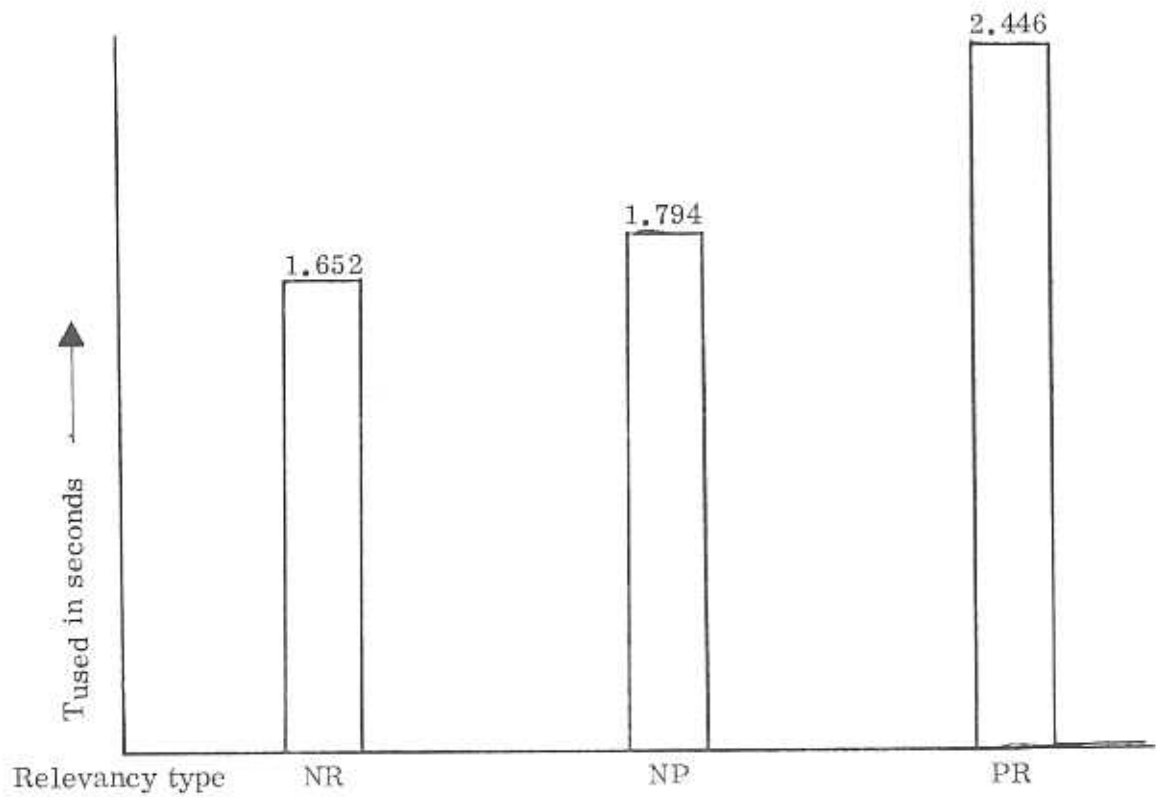


Figure 4.22. --Mean values of T_{used} for the three levels of signing relevancy for new signs on I-90

The results of the correlation coefficients suggest the following.

1. The sign reading behaviors of drivers for the old and new signs were different. Even though the measures T_{max} and T_f were significantly and positively correlated in both the signing conditions, for the old signs T_f and T_{used} were not significantly correlated. These results further suggest the following:

    a. The correlation between T_{max} and T_f appears to a more basic relationship in understanding the sign reading behaviors of drivers.

    b. Since T_f and T_{used} were not correlated for the old signs, it suggests that the values of T_f were much smaller and the values of T_e were larger (see Figure 4.15). The drivers had to adapt the stressful condition by concentrating their time-sharing process (as on the average the value T_i/T_{used} was smaller for old signs as compared to the new signs). (See Figure 4.24.)

    c. Further, the 85th percentile value of T_{max}/T_f for the old signs of relevancy type NR were much shorter than the signs of relevancy type NR in new signing. (See Figure 4.25.) This suggests that since the old signs did not provide adequate information, the drivers looked at the signs which did not provide relevant information with increased urgency; i.e., smaller values T_{max}/T_f. This behavior could have been a result of the drivers desperate attempts to acquire the required information due to insufficient signing information provided by the old signs.

2.3 The Effect of the Location of a Sign in the Sequence of Signs on the Sign Reading Behaviors of Drivers in Old and New Signing Conditions

Figures 4.25 and 4.26 present the data on sequential aspects of the old and new signing, respectively. In these figures, the percentage of signs read by the drivers (i.e., the signs for which $T_{used} > 0$) as a function of the number of sign location in the signing sequence are presented. In each of these figures three curves are presented. The three curves represent the data for the following: 1) for all signs; i.e., by aggregating data over signs of all the three types of relevancy, 2) for the signs of relevancy type PR, and 3) for the signs of relevancy type NP. For the signs of the relevancy of types NP and PR, the mean values of T_{used} are also presented in these figures.

Table 4.10

Correlation Coefficients Obtained for Old and New Signs
as a function of the Relevancy of Signing to the Driving Task

Signing Condition	Relevancy of signs to the driving task	MEASURES CORRELATED		
		T_{max} and T_f	T_f and T_{used}	T_{max} and T_{used}
Old Signs	NR	0.606***	0.265	0.249
	NP	0.402**	0.326*	0.008
	PR	0.611***	0.052	0.052
New Signs	NR	0.563***	0.577***	0.146*
	NP	0.713***	0.260***	0.180**
	PR	0.653***	0.360***	0.245**

Note: 1. The sample sizes used for obtaining the above correlation coefficients were as follows:
for Old Signs: 20 to 45, and
for New Signs: 67 to 123.

2. Hypothesis tested: (Note: ρ = correlation coefficient)
H_0: $\rho > 0$ vs. H_1: $\rho \leq 0$

Notation of significance levels:
* = $p < 0.10$
** = $p < 0.05$
*** = $p < 0.01$

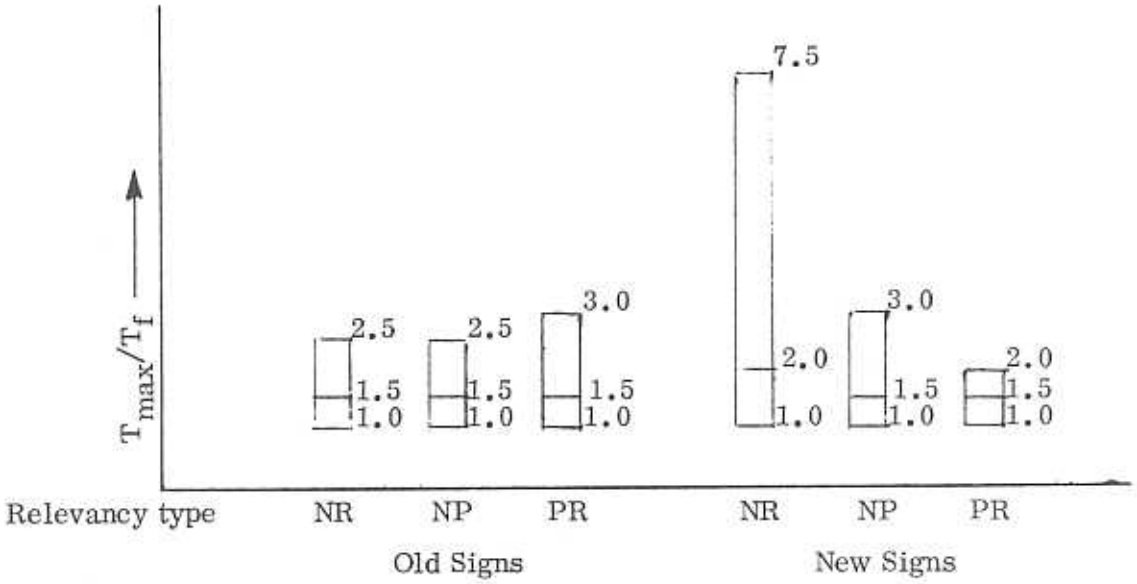


Figure 4.23.--Fifteenth, Fiftieth, and Eighty-Fifth Percentile Values of T_{max}/T_f as a Function of the Relevancy of Signing for Old and New Signs on I-90

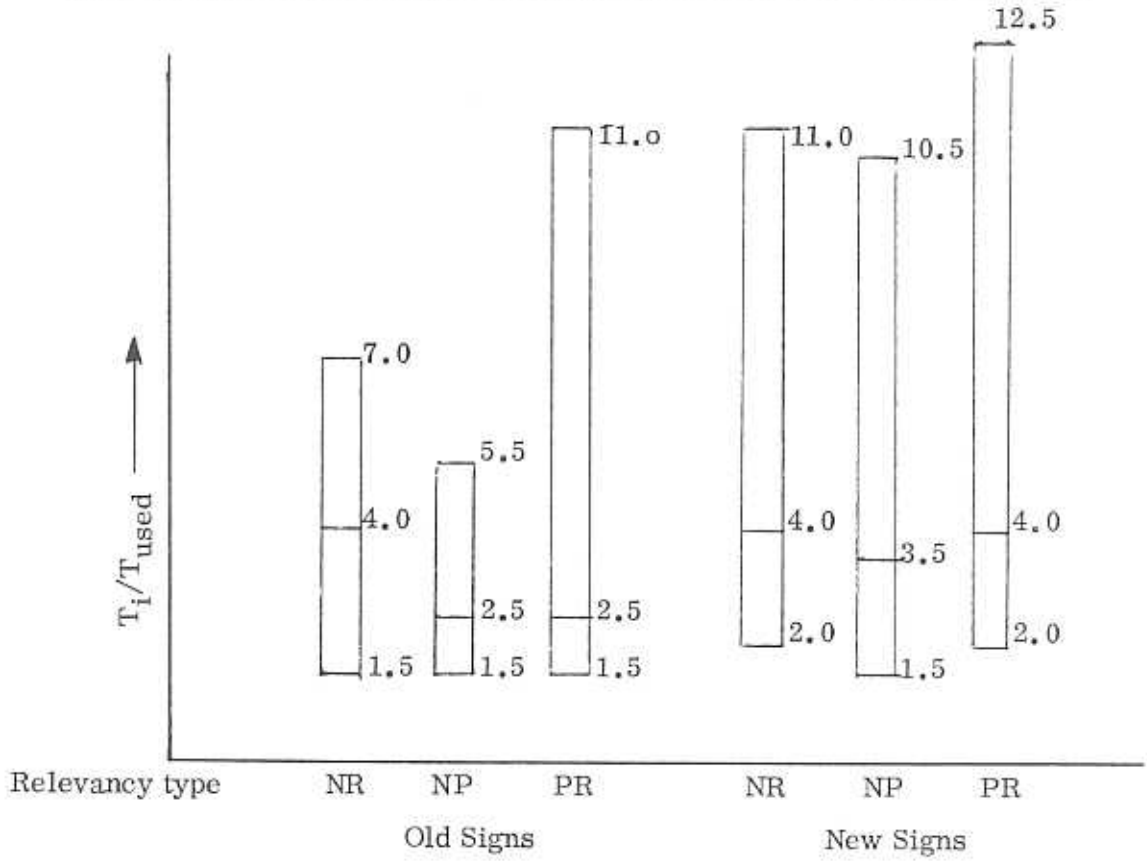
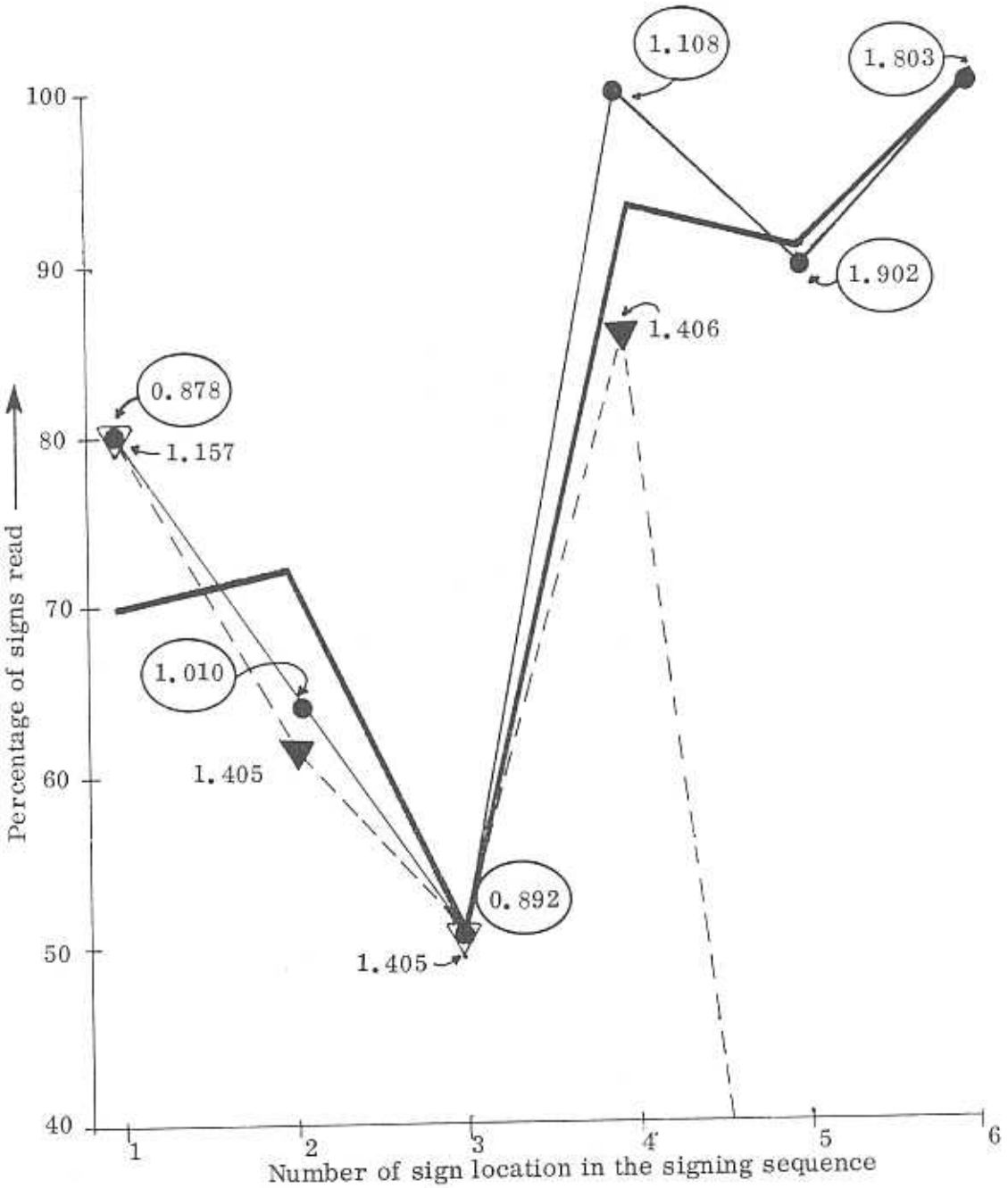


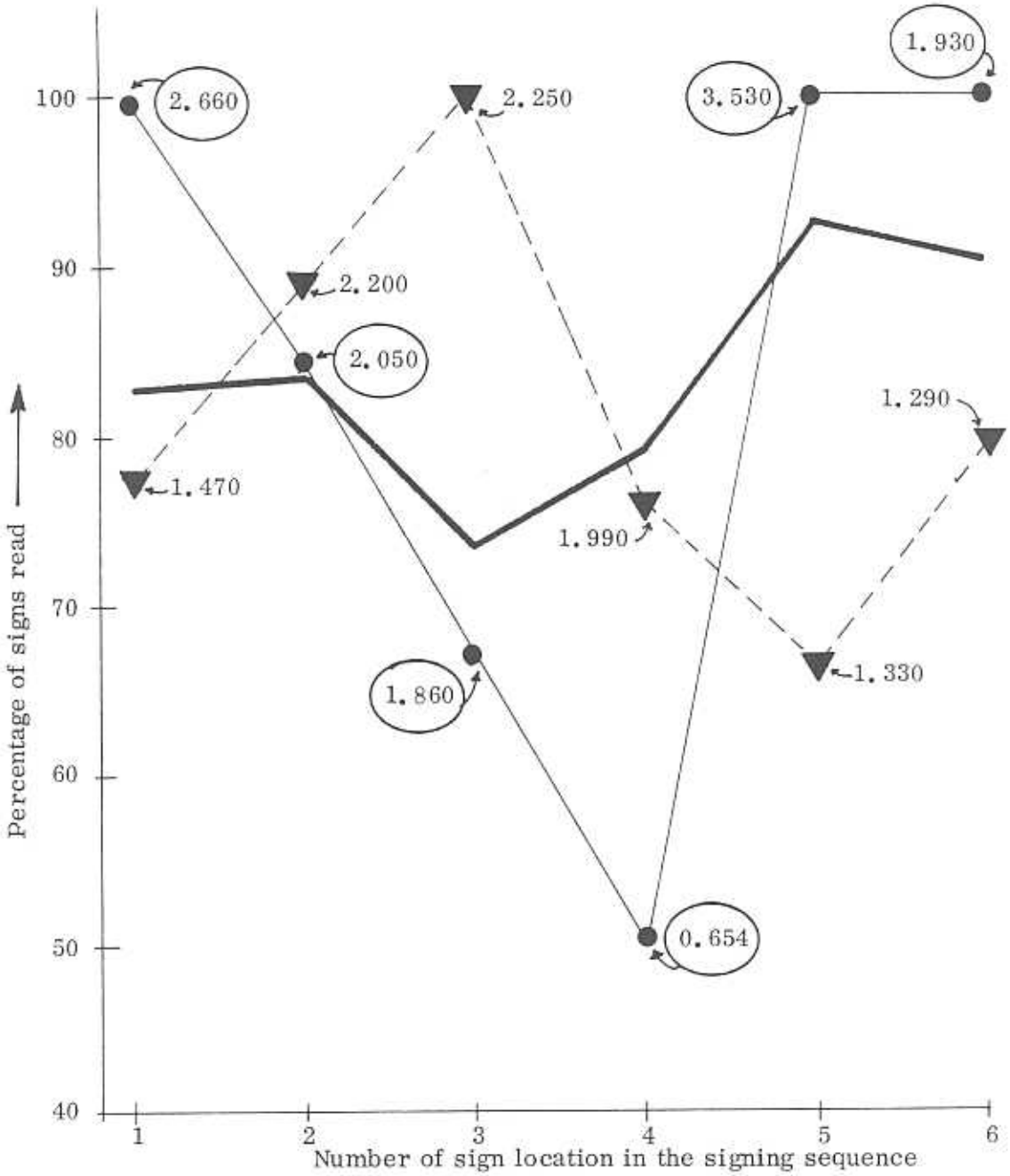
Figure 4.24.--Fifteenth, Fiftieth, and Eighty-Fifth Percentile Values of T_i/T_{used} as a Function of The Relevancy of Signing for Old and New Signs on I-90



Notation: ——— All signs; i. e., data aggregated over all types of relevancies
—●— Signs of relevancy type PR
—▼— Signs of relevancy type NP

Note: The numbers next to the data points represent the mean values of T_{used}. The uncircled and circled values are for the signs of relevancy types NP and PR, respectively.

Figure 4.25.--Percentage of Signs Read and the Mean Values of T_{used} as a Function of the Number of the Sign Location in the Old Signing Sequence



Notation: ——— All signs; i.e., data aggregated over all types of relevancies
—●— Signs of relevancy type PR
—▼— Signs of relevancy type NP

Note: The numbers next to the data points represent the mean values of T_{used}. The uncircled and circled values are for the signs of relevancy types NP and PR, respectively.

Figure 4.26.--Percentage of Signs Read and the Mean Values of T_{used} as a Function of the Number of the Sign Location in the New Signing Sequence

Before drawing conclusions from the data presented in the two figures, namely, Figure 4.25 and 4.26, it should be noted that there was considerable difference between the sequential design characteristics of the old and new signs (see Appendix A for details) and this primarily is due to the fact that there were two to three signs per exit for the old signing as compared to the four signing locations per exit for the new signing. Therefore, considering the above mentioned basic difference and taking into account the subject instructions, the following conclusions can be drawn from the data presented in the two figures.

1. The driver while driving through the old signing conditions had difficulty in detecting the first three signs as compared to the new signs.

2. Since the new signing involved use of multiple signs an interesting effect of switching attention between signs of type NP and PR is observed. The drivers while driving under new signing conditions placed more emphasis on the first sign of type PR in the sequence and then placed more emphasis on signs of type NP; but as they came closer to the exits they primarily looked at signs of type PR and the mean values of T_{used} in such cases were larger.

3. For the new signs, in general, the mean values of T_{used} and the percentage of signs read appear to be highly correlated.

3. The Results of the Level 3 Analyses

3.1 Effect of Driver Familiarity for the Old and New Signs

In the previous pages the results were presented by considering the data aggregated over the two levels of driver familiarity. It should be noted that under each signing conditions the drivers were asked to drive twice on the test route involving the six trials under the identical instructions. Thus, while driving the second time on the test route, the drivers were somewhat familiar with the test route and the signing on the test route.

Figures 4.27 and 4.28, respectively, present the data on percentage of signs read and the mean values of T_{used} for the old and new signs as a function of familiarity.

If it is hypothesized that with increase in familiarity the driver would spend less time reading a sign (as observed in studies F-5, L-1, and L-2), the data in Figures 4.27 and 4.28 would show interesting differences between the old and new signing conditions.

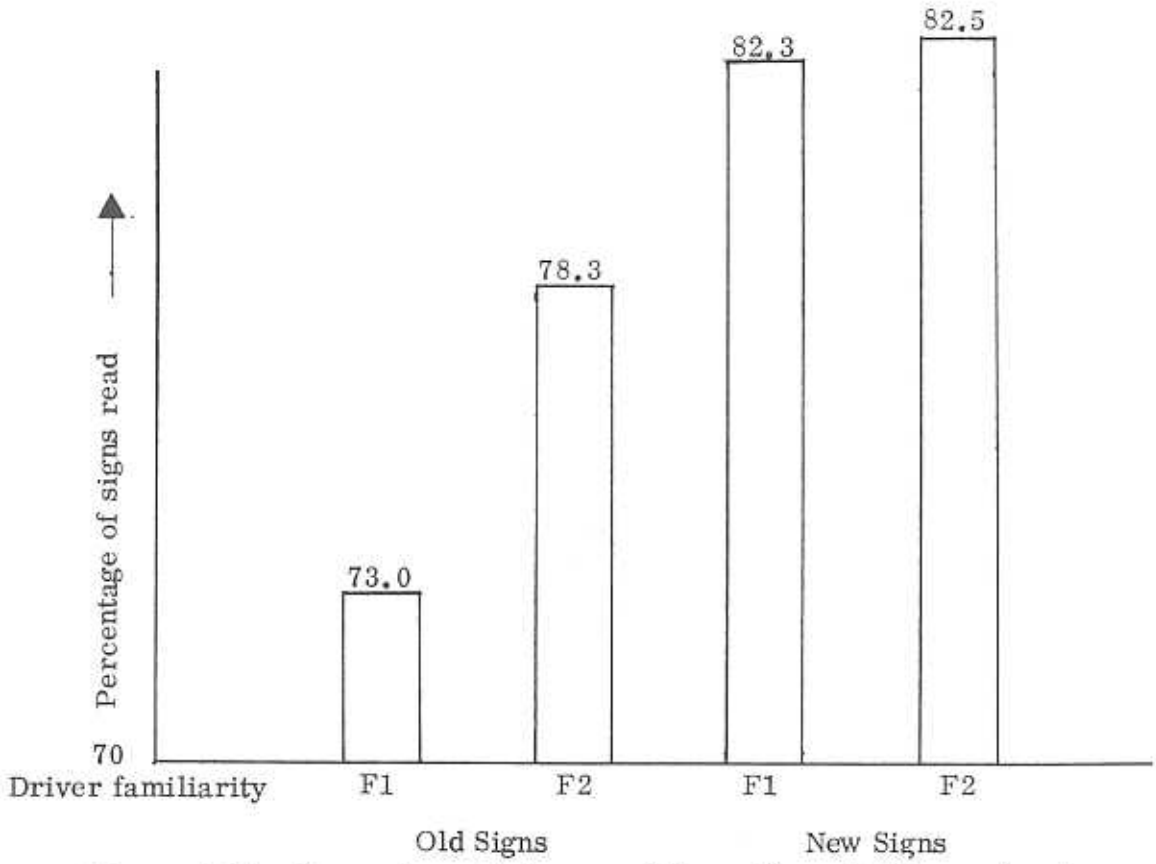


Figure 4.27.--Percentage of signs read (i.e., $T_{used} > 0$) as a function of driver familiarity for the old and new signs on I-90

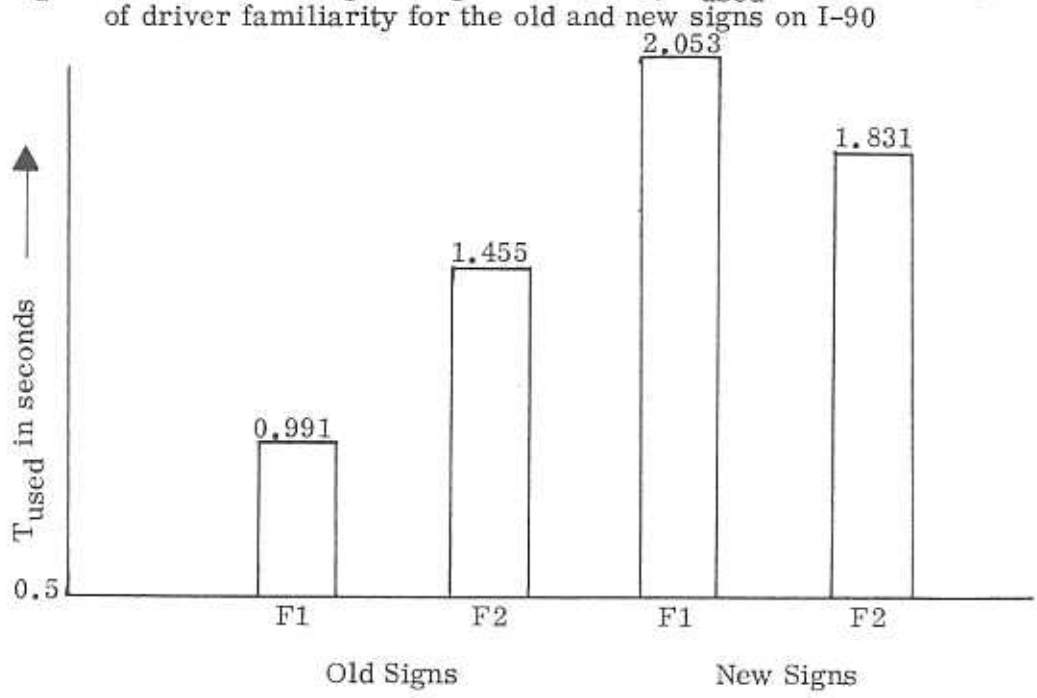


Figure 4.28.--Mean values of T_{used} (obtained for signing having $T_{used} > 0$) as a function of driver familiarity for the old and new signs on I-90

Table 4.11

Correlation of T_{used} and Driver Familiarity

Data on Signs Considered for Correlation	Correlation Coefficients of T_{used} and Familiarity	
	Old Signs	New Signs
All Signs (all relevancies combined)	0.207***	-0.057**
NR	0.456**	-0.068*
NP	0.311*	-0.028
PR	0.031	-0.080*
Hypothesis tested to obtain significance levels	$H_0: \rho > 0$ $H_1: \rho \leq 0$	$H_0: \rho < 0$ $H_1: \rho \geq 0$

Notation used to denote significance levels

* = $p < 0.25$
** = $p < 0.10$
*** = $p < 0.05$

1. The data shows that with increase in the driver familiarity under old signing conditions, the drivers actually looked at more signs and their mean values of T_{used} also increased. This effect is exactly opposite to the above presented hypothesis.

   It appears that this effect is primarily due to inadequacy of the old signing in presenting information to an unfamiliar driver. The old signs were difficult to detect when the drivers were driving the first time on the test route, and as a result due to no detection or late detection they could not read all the signs.

   In fact, all five test drivers could not find the Eddy Road exit when they drove for the first time on the test route.

2. The above discussed effect can be more clearly understood by observing the correlation coefficients of T_{used} and driver familiarity presented in Table 4.11. From the data presented in the Table 4.11, the following conclusions can be drawn.

   a. For the old signs, T_{used} was significantly and positively correlated to driver familiarity. This result suggests that as the driver got more familiar in the second run, he detected more signs and thus could spend more time reading the information presented by the signs.

   b. For new signing, the measure T_{used} was significantly and negatively correlated to driver familiarity. This suggests that since the new signing presented adequate information to the driver driving under no familiarity, he spent less time obtaining the same information while driving in the subsequent run.

3. Another interesting difference between the sign reading behaviors of drivers as a function of the signing differences is observed by observing the significance of the correlation coefficients obtained for the signs of relevancy types NP and PR. Table 4.11 shows that in the case of signs of relevancy types NP, T_{used} and the driver familiarity were significantly and positively correlated for the old signing but for the correlation for the same two variables under new signing was not significant. Exactly opposite effect is observed for the signs of the relevancy type PR.

   These two above effects primarily suggest that in both the signing conditions the drivers in the second run were reading more signs of relevancy of type NP as compared to the first run .

3.2 Determination of Differences Between Old and New Signing by Considering the Prediction of T_{used} as a Function of Signing Relevancy, Driver Familiarity and Message Content

Two stepwise linear regression analyses were performed to determine how the independent variables were related to the values of T_{used} obtained for the old and the new signs. The independent variables considered for the prediction of T_{used} were as follows:

1. Type of Relevancy (3 levels)
    a. type NR = 0
    b. type NP = 1
    c. type PR = 2
2. Driver Familiarity (2 levels)
    a. no familiarity (F1 = 1)
    b. second run (F2 = 2)
3. Content of Message Displayed by a Sign: The three following variables were considered to describe the message content:
    a. total number of letters (and numbers) displayed on a sign,
    b. total number of words displayed on the signs (note: The milage numbers and route numbers were regarded as a word.), and
    c. total number of lines in which the message was displayed on the sign.

Table 4.12 presents the results obtained from the two separate stepwise linear regression analyses; i.e., one for old signing and the other for new signing. The steps in which each of the independent variables used for the prediction of T_{used} for the two signing conditions were different, and these differences can be interpreted as follows:

1. The T_{used} for the new signs was very significantly related to the type of relevancy. The type of relevancy was the first variable that was introduced in the prediction of T_{used} regression, whereas, for the old signs it was the fourth variable introduced in the prediction.

Table 4.12

Results of the Stepwise Linear Regression Analysis used for Prediction of Tused as a Function of Signing Relevancy, Driver Familiarity and Message Content

	Significance levels of regression for the signing condition:			
	Old Signs		New Signs	
Independent Variable introduced in the step	Step No.	Significance Level	Step No.	Significance Level
Type of Relevancy	4	$p < 0.005$	1	$p < 0.005$
Driver Familiarity	2	$p < 0.005$	2	$p < 0.025$
Total No. of Letters on the Sign	3	$p < 0.005$	4	$p < 0.025$
Total No. of Words on the Sign	1	$p < 0.025$	5	$p < 0.050$
Total No. of Lines on the Sign	-	-	3	$p < 0.025$

2. The driver familiarity was the second variable that was introduced in both the linear regressions suggesting that it was the next important variable in the prediction of T_{used}, but its effect was observed to be in the opposite direction as described earlier.

Table 4.13 presents results of another set of six regression analyses performed on the data collected in this study. Since it is difficult to quantify the type of relevancy as done in previous regression analyses (i.e., Table 4.12) in this case, the data for each type of relevancy for each of the two signing conditions were treated separately for the stepwise regression analysis.

The results obtained from these analyses primarily suggest that for the old signs, the driver familiarity and the message content significantly affected the values of T_{used} for all the three types of relevancy, whereas, for the new signs, only the signs that presented information pertaining to the route were found to be significantly related to the variables describing the message content on a sign. It should be noted that the significance obtained by introducing the driver familiarity for the new signs of type PR was not very dominant.

When the above results are considered with our previous findings that, 1) in general, T_i/T_{used} was large for the new signs as compared to old signs and the finding, 2) that the values of T_{used} were larger for the new signs as compared to the old signs, it can be stated that the new signs did not require drivers to adapt and to load their sign reading behaviors as compared to the old signs.

Study F-5

Title: A Study for Determination of T_{reqd} Using a Programmable Research Sign

Objectives: The aim of this experiment was to obtain estimates of minimum time required by a driver to acquire necessary information from a sign as a function of the following factors:

1. length of message,
    a. number of lines,
    b. number of words in a line,
2. familiarity of the message to the driver, and
3. type of informational need.

Table 4.13

Results of the Stepwise Linear Regression Analysis Used for the Prediction of T_{used} for Signs of Each Type of Relevancy as a Function of Driver Familiarity and Message Content

Signing Condition	OLD SIGNS						NEW SIGNS					
Type of Relevancy	NR		NP		PR		NR		NP		PR	
Independent Variable introduced in the Step	Step No.	Significance Level	Step No.	Significance Level	Step No.	Significance Level	Step No.	Significance Level	Step No.	Significance Level	Step No.	Significance Level
Driver Familiarity	1	$p<0.025$	1	$p<0.050$	4	$p<0.025$	-	-	-	-	4	$p<0.250$
Total Number of Letters on the Sign	2	$p<0.050$	-	-	1	$p<0.005$	-	-	-	-	2	$p<0.100$
Total Number of Words on the Sign	3	$p<0.050$	-	-	3	$p<0.005$	-	-	-	-	3	$p<0.100$
Total Number of Lines on the Sign	4	$p<0.050$	2	$p<0.250$	2	$p<0.005$	-	-	-	-	1	$p<0.100$

The results of the previous field studies showed that the sign reading behaviors of the drivers are influenced by the type of information that a driver needs from a sign. Therefore, in the experiment the "type of informational need" was investigated by considering the following three types of information search by the drivers:

1. searching for required information which forms a part of the total message displayed by the sign; i.e., varifying the presence of information which is displayed on the sign (type IN 2),

2. searching for required information which is not displayed on the sign (type IN 3), and

3. searching for more specific (or additional) information in relation to required information (type IN 1).

The above three types of informational needs were created by including questions in the instructions presented to the subjects at the beginning of each trial. The questions and the instructions are presented on a later page in detail.

DESCRIPTION OF THE EXPERIMENT

Test Site: This experiment was conducted on a two mile section (east of Scottslawn Road entrance ramp) of State Route 33. This section of highway has two lanes in each direction and the experiment was conducted while driving eastbound in the left hand lane. The programmable research sign was mounted on a Rest Area Sign (type RA-3-132) which was located about a mile east of Scottslawn Road entrance ramp.

Description of the Programmable Research Sign

The programmable research sign used in the experiment is shown in Figure 4.29. This 12' x 6' overlay sign was mounted to cover an existing rest area sign. The sign was fabricated at the State Sign Shop of the Ohio Department of Highways and it was designed according to Ohio Standards to display four line messages presented in standard 10" E series upper case letters. The sign surface was coated with standard green reflectorized sheeting. On the front side of the sign grooved strips were spot-welded such that eight 6' x 1' green reflectorized aluminium plates could be slid in to form four line messages. The letters and numbers on these plates were made from standard white reflectorized tape material.

A total of eighteen different one line messages were selected for the experiment. The messages can be divided into two groups, each consisting of nine different messages. The two groups were as follows:

1. Group 1 - one word and one two digit number (e.g., "WESKET 30"), and

2. Group 2 - two words and one two digit number (e.g., "BREMEN PLAZA 28").

Experiment Design

The experiment design of the study is presented in Table 4.14. Four college age male subjects with normal vision participated in this experiment. Each subject was asked to participate in twenty-four trials. Each subject completed twelve trials in one afternoon session. In order to obtain the effect due to familiarity, the two afternoon data collection sessions for each subject were conducted with an interval of two days.

The details concerning the twelve trials are presented in Table 4.15. Each subject, thus,went through the same twelve trials (arranged in random order) in two afternoon sessions to obtain the effects of familiarity. Each trial consisted of entering the highway at Scottslawn Road entrance ramp and driving in the left lane for about 1-1/2 miles. The research sign was about 3/4 mile from the entrance ramp and as the subject approached the research sign, the experimenter then directed the subject to take a 'U' turn and drive back to Scottslawn Road for the next trial.

It should be noted that in order to prevent other drivers (i.e., traffic) from getting confused by the research sign, another sign (type N-113-60, special) displaying the message "RESEARCH SIGN AHEAD" was mounted at a distance of 1/2 mile upstream of the location of the research sign.

Subject Instructions

Before the beginning of an afternoon session the subject was given the following instructions:

> The purpose of this experiment is to measure your lateral control precision while acquiring exiting information from a sign. You will be required to drive to the best of your ability in the middle of the left hand lane. You will be paid bonus money for precise accomplishment of this task. You will be also required to answer questions about our experimental sign. After each run (trial), the data on the sign will be changed and you will be asked a new question before each run. During each run you will be told when you will be able to read the sign, so that you need not look until you are told to do so.

Figure 4.29.--The Programmable Research Sign used in Study F-5

Table 4.14

Experiment Design of Study F-5

No. of Lines		2L				4L			
Words/Line		1W + N		2W + N		1W + N		2W + N	
Familiarity		F 1	F 2	F 1	F 2	F 1	F 2	F 1	F 2
Type of Informational Need	IN 1								
	IN 2								
	IN 3								

Note:

L = Lines
W = Word
N = Two digit number
F = Familiarity
IN = Informational need
Subjects used = 4

Table 4.15

Details of Twelve Trials Conducted for Each Subject in One Afternoon Session

TRIAL NUMBER	MESSAGE ON SIGN	TYPE OF INFORMATION NEEDED	ABSTRACT OF SUBJECT INSTRUCTIONS	CORRECT ANSWER
1	Tremont 16 Summit 19 Dexter 20 Funstock 64	1	Miles to Dexter?	20
2	Summit 19 Swisher 22	2	Is Summit ahead?	Yes
3	Francis Terrace 18 Condid Avenue 39 Bishof Drive 23 Colcut North 92	3	Is Colony North ahead?	No
4	Bishof Drive 23 Biretta Street 25	2	Is Bishof Drive ahead?	Yes
5	Funstock 64 Fondorf 46	3	Is Fremont ahead?	No
6	Wesket 30 Weldon 51	1	Miles to Weldon?	51
7	Frantiz Road 81 Biretta Street 25 Colcut North 42 Bremen Plaza 28	1	Miles to Frantiz Road?	81
8	Cosine South 29 Colcut North 92	3	Is Condid ahead?	No
9	Dexter 20 Carter 27 Funstock 64 Tremont 16	2	Is Carter ahead?	Yes
10	Frantiz Road 81 Francis Terrace 18	1	Miles to Francis Terrace?	18
11	Carter 27 Wesket 30 Swisher 83 Funstock 64	3	Is Bremen ahead?	No
12	Frantiz Road 81 Cosine South 29 Condid Avenue 39 Bremen Plaza 28	2	Is Cosine South ahead?	Yes

It should be noted that in the above instructions the subject was asked to drive the vehicle in the center of the left lane. This task was intended to keep the driver visually loaded. In addition to this task, the bonus money was offered to the subjects and the intent of this was to motivate the subjects in obtaining the required information from the sign as quickly as possible. The instructions, thus, prevented drivers from staring at the research sign.

It should be noted that prior to the data collection runs, the subject was asked to drive at 60 mph in the left hand lane and was asked to stare at the sign and read a test message "loudly" as soon as it became legible. The maximum sight distance from which the subject could read the test message was thus established. In the subsequent data collection runs, the subject was told to look at the sign immediately after he passed the maximum sight distance. It should be noted that the test message did not contain any of the data that was presented on the sign for the data collection trials. The displayed test message was presented in the same letter sizes and type as the data presented during experimental trials.

At the beginning of each trial the subject was given the following instructions:

> Drive at 60 mph in the middle of the left hand lane. Do not look at the sign until your experimenter commands, "You may look." As soon as you are able, answer the following question.

One of the following three questions, depending upon the type of informational need, was then presented the subject.

TYPE OF INFORMATIONAL NEED	INSTRUCTIONS
IN 1	You desire to exit at _____. How many miles further do you have to drive? (See trial numbers 1, 6, 7, and 10 in Table 4.15.)
IN 2	You desire to exit at _____. Does this sign give you any information as to such an exit? (See trial numbers 2, 4, 9, and 12 in Table 4.15.)
IN 3	You desire to exit at _____. Does this sign give you any information as to such an exit? (See trial numbers 3, 5, 8, and 11 in Table 4.15.)

It should be noted that the difference in informational need between type 2 and 3 is due to information presented on the sign. Under trials of type 2 informational need the desired exit was displayed on the sign, whereas, under trials of type 3 informational need, the desired exit was not displayed on the sign.

Results

During all the trials conducted in this experiment, the eye movements of the drivers and their verbal answers to the questions were recorded. Out of the 96 trials conducted for the four subjects, only three incorrect responses were made, two by subject KF and one by subject FS. Subjects DF and HU responded to all answers correctly.

The time taken by subjects in obtaining information from the signs was obtained by counting the film frames in which the subjects directed their eyes towards the sign. These fixations were easily identified by the help of the stimuli, which the experimenter recorded on the film by pushing a switch (which lighted a bulb at an end of the beam splitter in the output system of the eye marker camera system) at two instances. The experimenter first pushed the stimulus switch when he commanded the driver to look at the sign and then he pushed the stimulus switch again when the driver just passed the research sign.

The time taken by subjects to obtain information to answer questions for each of the trials was considered as response or dependent variable (T_{reqd}). The data obtained was then analyzed by using the analysis of variance technique (ANOVA)*. A simple fixed factor analysis of variance model for the experiment design presented in Table 4.14 was used by considering the following four factors:

1. familiarity (2 levels),
2. type of informational need (3 levels),
3. number of lines (2 levels), and
4. number of words per line (2 levels).

The subjects were considered as replicates.

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*The analysis of variance is one of the most powerful tools for statistical analysis. Basically, it consists of classifying (according to levels of factors) and cross-classifying (combination of levels of different factors) statistical results and testing whether the means of a specified classification (levels of a factor) differ significantly. In this way, it is determined whether the given factor is important in affecting results.

Table 4.16 presents the most important results obtained from the ANOVA test. Figures 4.30 and 4.31 present the marginal means and cell means, respectively, obtained from the analysis of the data obtained from the study. From the data presented in Table 4.16 and Figures 4.30 and 4.31, the following conclusions can be drawn.

Conclusions

1. The amount of message displayed by the sign significantly affects the minimum reading time required to obtain information from the sign. The two variables, number of lines of message on the sign, and the number of words per line, both were found to be statistically significant ($p < 0.005$). The Figures 4.30 (c) and 4.30 (d) both show that with increase in number of lines and number of words per line, the minimum time necessary to acquire information presented on a sign increases.

2. T_{reqd} is significantly ($p < 0.025$) affected by familiarity of the driver with the message. It should be noted that for all the four subjects the trials under F1 and F2 conditions were separated by an interval of two days and the average difference in the marginal means was 318 msecs.

3. The variable IN, the type of information need was found to affect T_{reqd} significantly ($p < 0.025$). This result, thus, strongly confirms the hypothesis that the amount of time a driver requires to obtain required information from a sign depends upon his objectives; i.e., his informational need.

The results presented in Figure 4.30 (b) further shows that drivers spend considerably more time in searching for information from the sign when the information that is required is not presented on the sign. (Note: 2.361 - 1.895 = 0.566 sec. is the average difference between IN 3 and IN 2 conditions.)

Further, the difference between the mean values of T_{reqd} for IN 1 and IN 2 conditions is positive. The difference indicates the time required by the drivers to obtain milage information in IN 1 type tasks as compared to the task demanded in IN 2 which did not include the milage information. Thus, to obtain this additional milage information, the drivers spend on the average 2.142 - 1.895 = 0.247 seconds.

4. Table 4.16 and Figure 4.31 show that some interactions between different factors were significant. The most significant interactions were due to W x L and F x IN x W. The interactions appear to be significant due to the following factors:

Table 4.16

Results of ANOVA for Determining the Effects of Different Factors on T_{reqd}

	Source of Variation	F. Ratio	D. F.	Significance Level
Due to differences between levels of the factor*:	Lines (L)	11.00	2,72	$p < 0.005$
	Words (W)	8.67	1,72	$p < 0.005$
	Familiarity (F)	6.43	1,72	$p < 0.025$
	Type of Informational Need (IN)	4.59	1,72	$p < 0.025$
Due to interactions** between levels of different factors:	F x IN	2.10	2,72	$p < 0.025$
	IN x W	1.59	2,72	$p < 0.025$
	W x L	4.75	1,72	$p < 0.025$
	F x IN x W	3.75	2,72	$p < 0.025$

Note:

1. Only the statistically significant findings are presented in this table.
2. * = effect of a factor. The change in response (i.e., T_{reqd}) produced by a change in the level of a factor.
3. ** = interaction. A relation between two factors in which a change in the response (T_{reqd}) between levels of one factor is not the same for all levels in the other factor.
4. See Table 4.14 for factor levels.

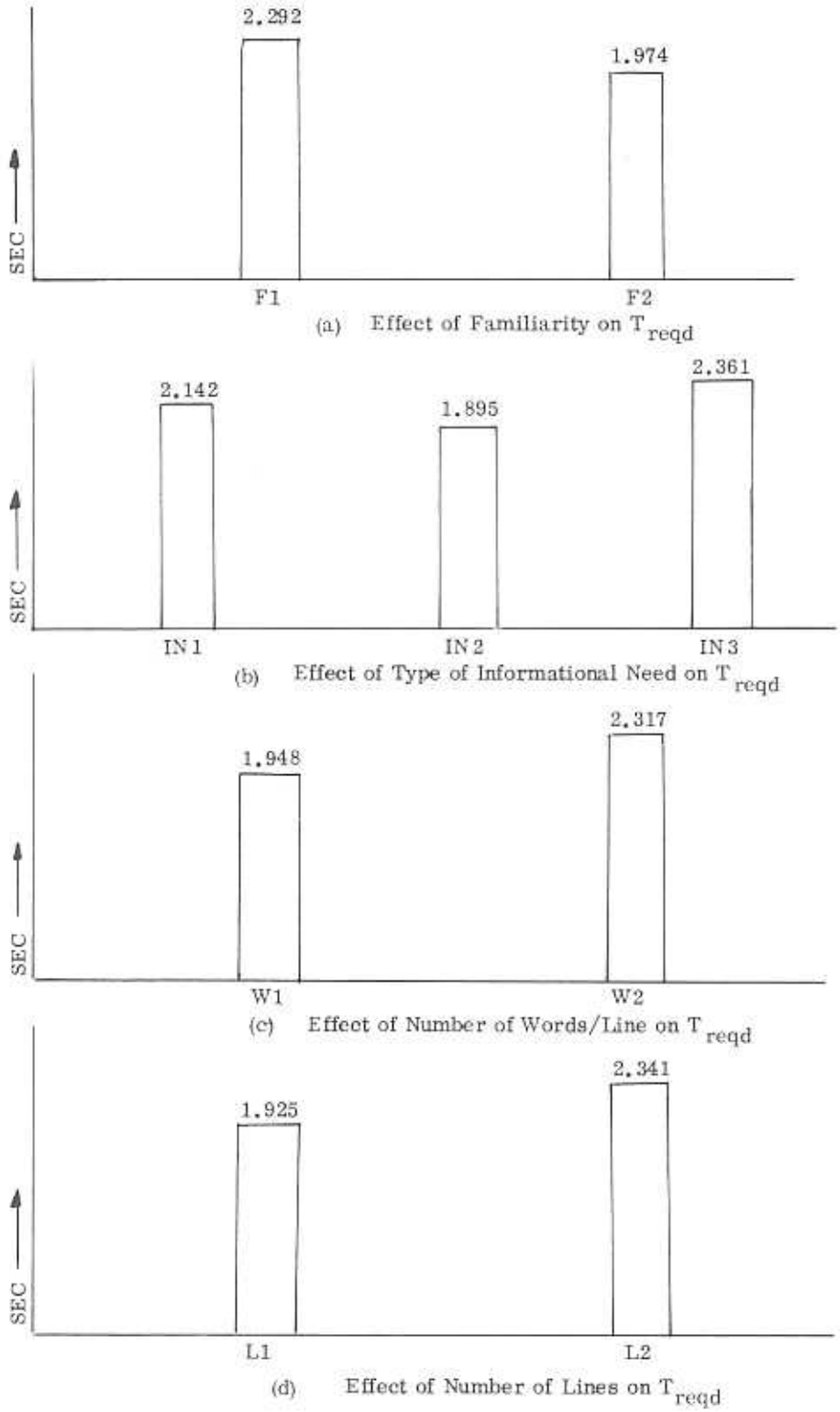


Figure 4.30.--Marginal Means of T_{reqd} Obtained as a Function of Levels of: a) Familiarity, b) Type of Informational Need, d) Number of Words/Line, and d) Number of Lines on the Sign

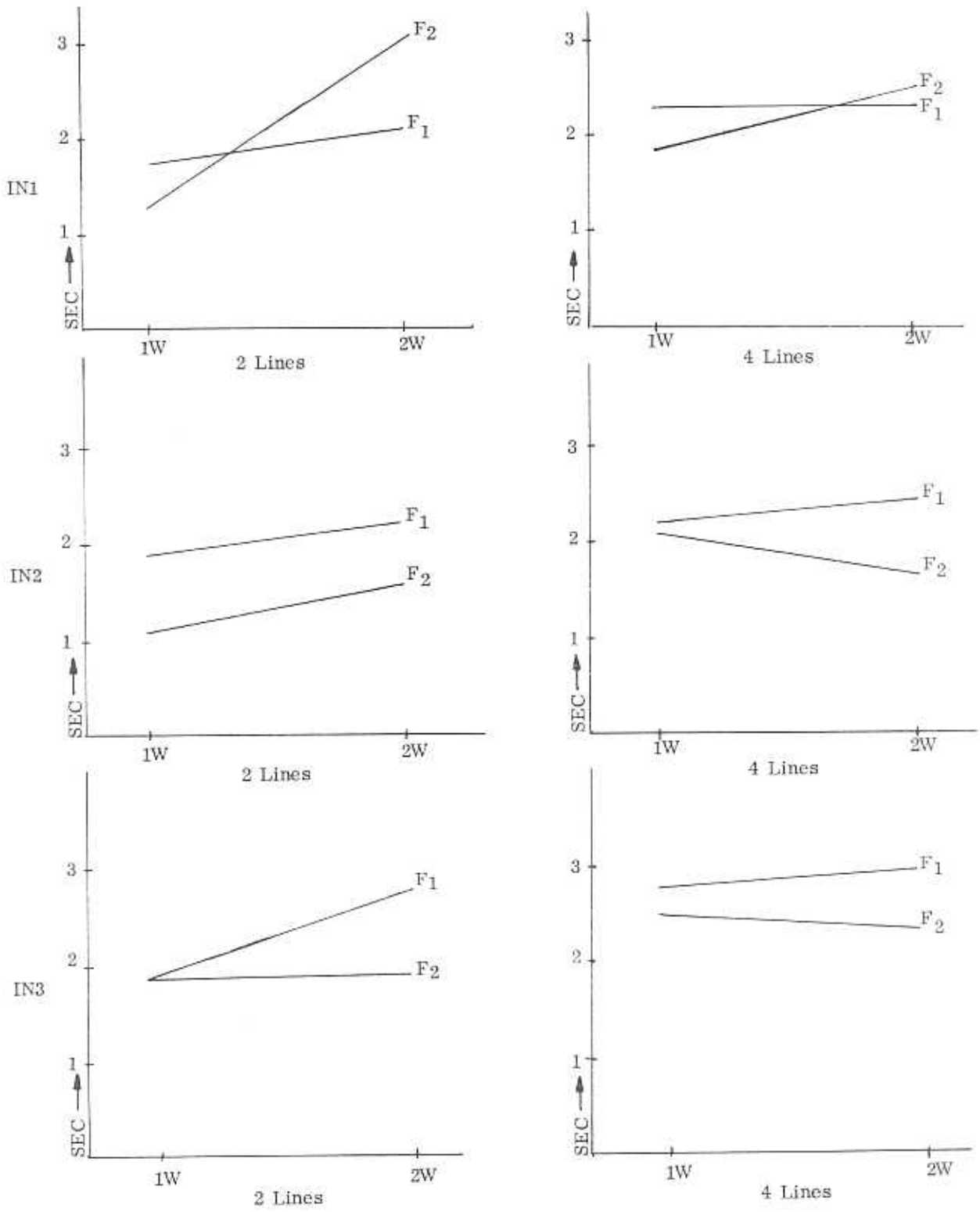


Figure 4.31.--Graphical Illustration of Cell Means of T_{reqd} Obtained from Study F-5

a. spatial differences in visual search patterns of drivers in relation to required information on the sign, and

b. differences between words and the driver's familiarity with the words.

The differences mentioned in a. above were investigated. Figure 4.32 illustrates how two subjects obtained information from the sign in trial number 6. From this illustration, it appears that the differences are due to the positions of first one or two fixations that the drivers make in relation to the required information. The effect of position of needed information displayed on the sign on T_{reqd} was, therefore, investigated later in study L-3.

Study F-6

Title: A Study for the Investigation of the Effects of Sequential and Multiple Signs on the Sign Reading Behaviors of Drivers

Objectives: The primary objectives of the study were to determine the effects of the variables presented below on the sign reading behaviors of drivers and to attempt to enrich the developed methodology by implementing the findings of the study.

The independent variables considered for the study were:

1. number of signs per location (multiple signs), and

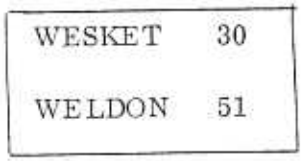
2. number of locations of sign (or signs) per exit; i.e., number of sequential signs per exit.

DESCRIPTION OF THE EXPERIMENT

For the purpose of this experiment signing sequences on I-270, I-71, and I-70 were first surveyed and from the survey sixteen different signing sequences were selected. The signing sequences were so selected that two examples of signing sequences of each of the eight combinations presented in Figure 4.33 were obtained. The locations of the selected signing sequences and the listing of the signs in each of the sequences are presented in Appendix A.

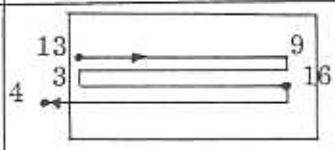
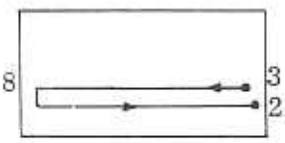
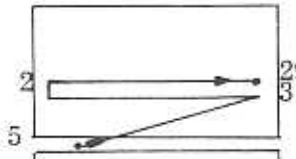
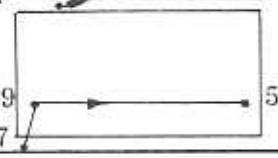
Since the results obtained from study F-1 indicated that the level of visual load on the drivers' information acquisition and processing activities highly influence the sign reading behaviors of the drivers; i.e., the unloaded drivers tend to stare at the signs excessively, in this experiment the driving task was so designed that it would impose high visual loading on the drivers. This was achieved by

Details of Trial 6



Informational Need:
Miles to Weldon?

Sketch of sign showing
message displayed in Trial 6

Subject	Familiarity Level	Spatial Plot* of Fixations	No. of Fixations	T_{reqd} in seconds
FS	1		5	2.32
FS	2		3	1.91
KF	1		4	2.21
KF	2		3	1.33

*Note: The arrows indicate the direction of successive eye movements. The numbers indicate duration of fixations in units of $1/16^{th}$ of a second.

Figure 4.32.--An Example Illustrating Differences in Spatial Search Patterns of Drivers in Trial 6

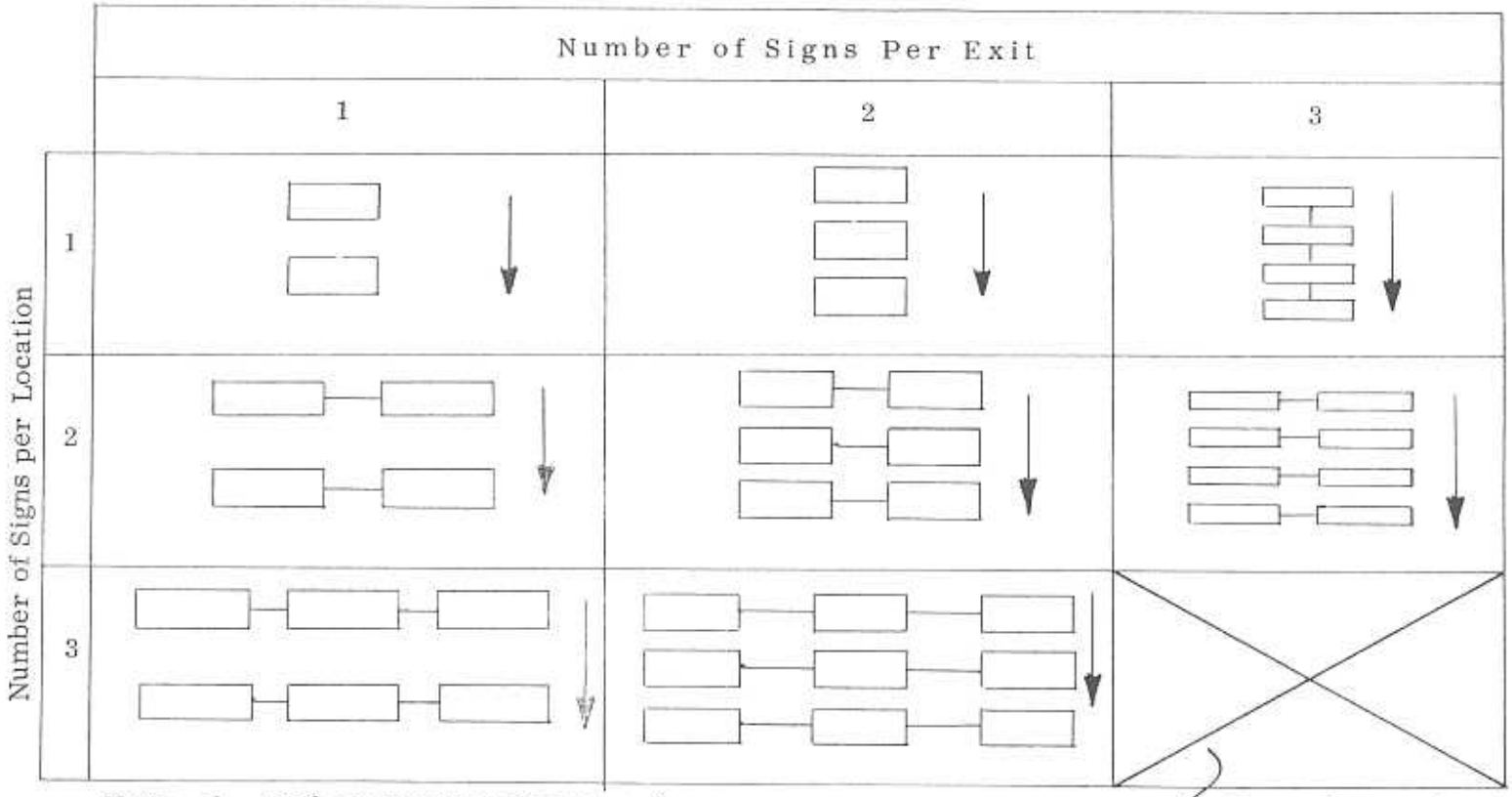


Figure 4.33--Experiment Design for Studying Sequence of Signs and Multiple Signs.

collecting data under a car-following mode and asking the drivers to stare at the lead car as much as possible and to exit at a specified exit. The subject instructions prior to each of the data collection runs were, therefore, as follows:

> In this trial we would like you to follow the lead car at exactly 125 feet and stare at the lead car as much as possible. We want you to perform this task until you reach _x_ exit. We would then like you to exit at _x_. The lead car will not exit with you. During this trial if you need to change lanes, please let us know and we will tell you when it is safe to do so.
>
> Are there any questions?

It should be noted that in the above instructions at the place of _x_ the name of the exit (or route) for the trial was specified to the subject. The lead car in all the runs was driven at a constant 65 mph speed.

Results

At the time this final report was prepared only about one-third of the total data (note: total data = data of three subjects collected over the sixteen test routes) was processed by using SEADEM II. Therefore, in order to avoid delay in the publication of this report it was decided to report the findings on the basis of the partial data in this report. A more complete analysis of the data will be conducted at a later date and the results will be reported in the Final Report of another research project entitled, EES 407 B: "Implementing Sign Research Results Into Operational Practices."

On the basis of the partial data analyzed from this study the following conclusions can be drawn:

1. Table 4.17 presents 15th, 50th, and 85th percentile values of sign evaluation measures obtained by aggregating the data for over the three subjects and over all the analyzed runs. When the data presented in Table 4.17 is compared with similar data obtained from studies F-1 and F-4, it is obvious to note that the instructions of car following and staring at the lead car as much as possible, visually loaded the drivers. The values of T_{max}/T_f were, in general, higher (as compared to those obtained in studies F-1, condition A, and F-4) indicating that the subjects tended to decrease T_f. It should be noted that an exactly similar effect was observed in study F-1 (i.e., comparing the values of T_{max}/T_f for condition A with the car-following conditions B and C). Further, the results show that the values of T_i/T_{used} were smaller (as under normal driving and low levels of loading the 50th percentile values of T_i/T_{used}, in general, lie between 3.0 to 4.0).

Table 4.17

Values of Sign Evaluation Measures Obtained
by Aggregating (Partial Available) Data
over Subjects and Test Routes

Measure	Percentile Values			Mean
	15%	50%	85%	
T_{max}	10.0	12.5	15.0	12.64
T_{used}	1.0	1.5	4.0	1.84
T_e	0.5	1.0	2.0	1.24
T_f	2.5	6.0	8.5	5.64
T_i/T_{used}	1.5	2.0	5.5	2.82
T_{max}/T_f	1.5	2.5	5.0	2.92

Thus, when the above two findings are put together, they indicate that due to the instructions of car following and staring at the lead car, T_f was shortened and as a result the drivers had to concentrate their time-sharing process with the signs much more heavily. Further, it was found that significant positive correlations were obtained between the following two pairs of measures:

a. T_{max} and T_f, and

b. T_f and T_{used}.

2. The drivers, in general, spent more time looking at the first and last (one or two) locations of signs in the sequence of signs. Such signs usually had lower values of both the measures, T_i/T_{used} and T_{max}/T_f.

3. In case of the multiple signs, the drivers, in general, spent more time looking at the signs which presented information pertaining to the route (or exit) as compared to the signs which did not present information pertaining to the drivers' intended route.

As stated earlier, the above results are based on the analyses of partial data obtained from this study. The remaining data on this study will be analyzed in the future and more detailed results of the study will be made available in the final report of the project, EES 407 B, which is a follow-on study being conducted for implementing the results obtained from the research results obtained from this project.

Study F-7

Title: A Study of Signing Providing Information Contradictory to the Geometric Highway Design in the Akron Area

Objectives: There were two primary objectives in conducting this study. One objective was to investigate the sign-reading behaviors of drivers when they are confronted with obtaining route guidance information from the signs which provide information contradicting to the geometric design of the highway; e.g., the signing requiring a turn to South in order to eventually end up going North. The second objective was to apply the developed methodology to the data obtained for such signing to study the evaluation capability of the methodology.

Test Site

For the purpose of this experiment many different test sites with different geometric configurations were surveyed. During the search of the suitable test sites, the officials of the Ohio Department of Highways were informally consulted to suggest the locations of what are the most commonly considered as the "problem interchanges"; i.e., the interchanges, about which the highway engineers received complaints by the users, because of the contradictory and confusing nature of the signing in relation to the geometric configuration of the highway. From the survey, three interchanges in the Akron area were selected for this study (see Figure 4.34). The Akron area was primarily selected for two reasons. The first reason was that all the three interchanges were separated by distances of less than 10 miles and they all had geometric features that could meet the objectives of this study. Further, since none of the subjects used in the previous studies in this research were familiar with the Akron area, the data collected while approaching these interchanges by using the same subjects was considered to be important. As the use of these subjects guaranteed that the collected data would be free from the effects of the highway familiarity and also it provided a unique opportunity to enable comparison of the data obtained in this study with the data obtained from the previous studies in which the same subjects were used.

DESCRIPTION OF THE EXPERIMENT

Five subjects (namely, subjects RH, KF, PZ, CS, and FS) participated in this experiment. The experiment consisted of the collection of the driver eye movements and driving performance data for each of the five subjects on the following three test routes.

Route 600: Entering I-80 S (East) at Barber Road and exiting at State Route 8 (North). This test route, thus, passed through all the three interchanges; i.e., interchanges A, B, and C in Figure 4.34.

Route 700: Entering I-80 S (West) from State Route 8 (South) and then taking I-277 (East) and exiting at Main Street. On this test route the data was collected while approaching and passing through the interchanges B, A, and while exiting at Main Street.

Route 800: Entering I-277 (West) at Main Street then getting on I-80 S (East) and then finally getting on I-77 (North). On this test route the data was collected while approaching and passing through the interchanges A and B.

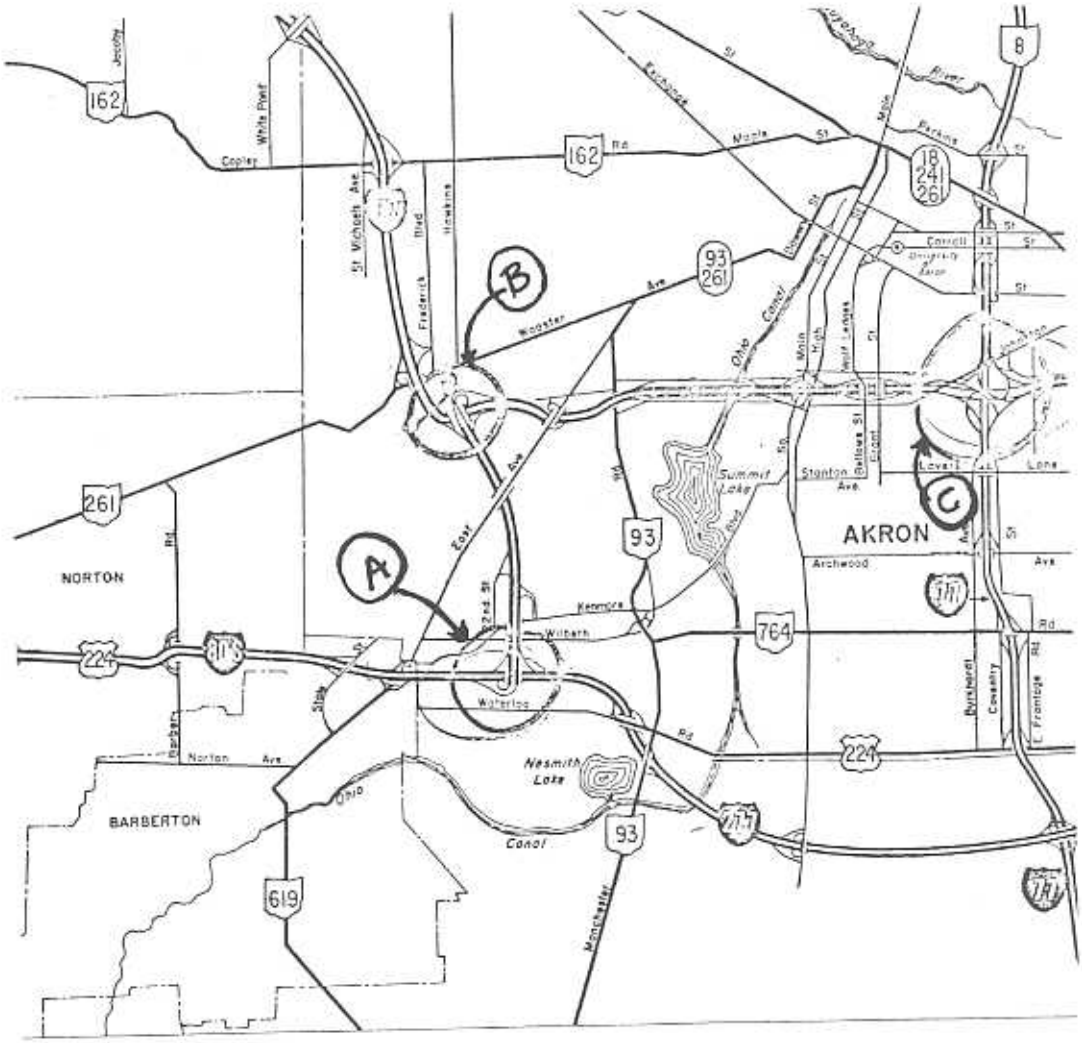


Figure 4.34.--Map of Akron area showing the three interchanges used in Study F-7

Each of the above test routes was further divided into sub-routes according to different characteristics of the geometric design of the highways. For example, the test run 600 was divided into three sub-routes, namely, sub-routes 601, 602, and 603. Figure 4.35 shows the paths of the drivers through the interchanges in the different sub-routes. While following the test route 600, the driver first approaches interchange A, where in order to keep continuing on I-80 S (East), he has to get off from the mainstream to the right; i.e., in a direction which is opposite to where I-80 S (East) continues. The details of this sub-route 601 are presented in Figure 4.35. Thus, from the sketches presented in Figure 4.35, it is clear that in the sub-routes 601, 701, 702, and 802, the drivers had to turn in a direction opposite to the final heading of the highway in order to keep continuing on that highway. The test sub-routes 602 and 801 are the examples where the interstate highway takes a turn on the right, whereas, the continued section of the highway; i.e., the mainstream, becomes a different interstate highway. The sub-route 603 was studied primarily as it required the driver to exit from the left hand side, whereas, sub-route 703 included the most common situation; i.e., exiting from the right hand side.

A list of the signs that the drivers encountered while passing on each of the above test routes are presented in Appendix A.

Subject Instructions

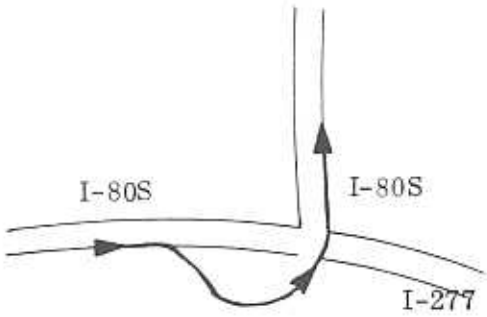
Test Route 600: Prior to entering on the entrance ramp at Barber Road, the following instructions were given to the subjects.

"We would like you to enter I-80 S heading east, and drive on I-80 S (East) in your normal manner until you reach State Route 8. We would then like you to exit at State Route 8 heading north. During this run if you desire to change lanes, please tell us and we will let you know when it is safe to do so."

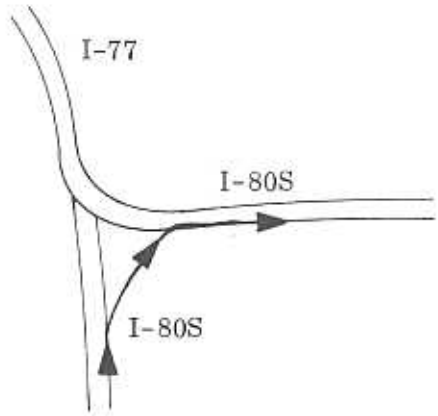
"Are there any questions?"

It should be noted that in the above instructions, the instructions concerning the lane changes were included primarily to avoid excessive large head movements which could disturb the calibration of the eye-marker camera system used to record the driver's eye movements. If the subject had any questions, then the above instructions were presented to him again.

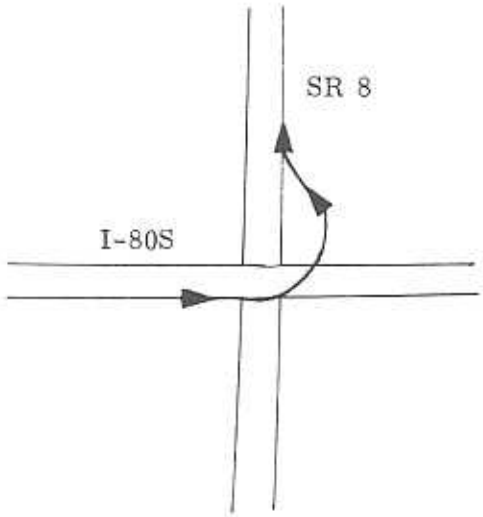
Test Route 700: While traveling on State Route 8 heading south (before the interchange C) a subject was given the following instructions.



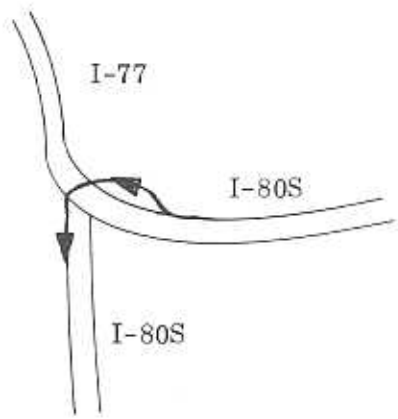
Sub-route 601
(Interchange A)



Sub-route 602
(Interchange B)

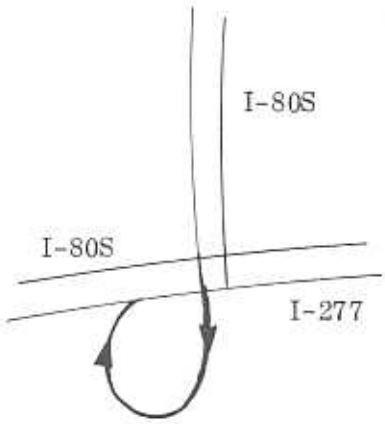


Sub-route 603
(Interchange C)

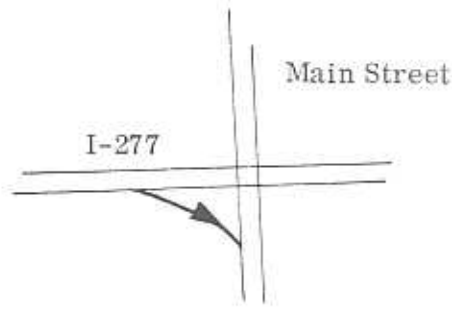


Sub-route 701
(Interchange D)

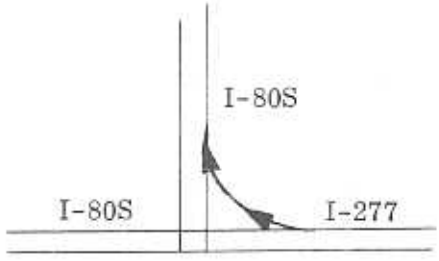
Figure 4.35.--Sketches of interchanges showing the test sub-routes



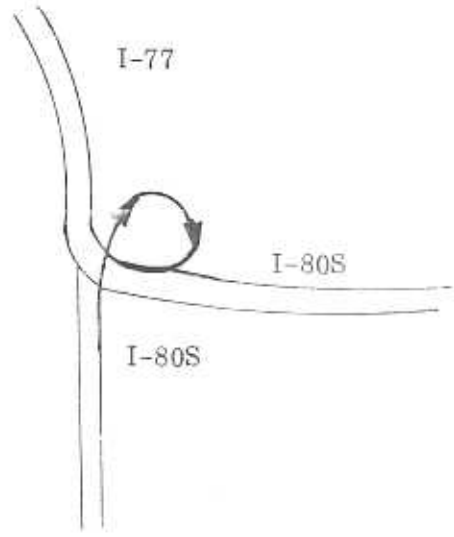
Sub-route 702
(Interchange A)



Sub-route 703



Sub-route 801
(Interchange A)



Sub-route 802
(Interchange B)

Figure 4.35 (Continued)

"In this run, we would like you to enter I-80 S heading west. We would like you to continue on I-80 S (West) until you come to I-277 junction. We would like you then to get on I-277 heading east and then exit at Main Street. During this run, if you desire to change lanes, please tell us and we will let you know when it is safe to do so."

"Are there any questions?"

Test Route 800: While parked near the entrance ramp at Main Street, a subject was given the following instructions.

"We would like you to enter I-277 heading west and drive in your normal manner until you reach I-277 - I-80 S interchange. At this interchange we would like you to get on I-80 S heading east. We want you to continue on I-80 S (East) until you come to I-77 - I-80 S interchange. We would then like you to get on I-77 heading north. Thus, summarizing, you have to follow I-277 (West), I-80 S (East) and then I-77 (North). During this run, if you desire to change lanes, please tell us and we will let you know when it is safe to do so."

"Are there any questions?"

Results

The data obtained for all the subjects while traveling on each of the sub-routes was analyzed by using the computer program SEADEM II. The sign evaluation measures obtained from SEADEM II were then further analyzed to determine the differences in the sign reading behaviors of the drivers on each of the sub-test routes.

For this purpose, the data for all the signs on a sub-route and for the subjects used on that sub-test route was aggregated. On the aggregated data, eight separate correlation analyses for the eight sub-routes were performed. The Bio-Medical computer program, BMDO3D, was used for the analysis and the following twelve variables were considered for the computation of means, variances, and correlation coefficients:

1. T_{max},

2. T_{used},

3. T_e,

4. T_f,

5. T_i,

6. total number of fixations presenting resolvable information of the sign to the driver,

7. T_{max}/T_{used},

8. T_{max}/T_i,

9. T_i/T_{used},

10. T_{max}/T_f,

11. K_1 = the number of logitudinal location of the sign; i.e., the number of the sign location in the sequence of signs, (see Figure 3.4 for illustration), note $K_1 = 1$ denotes the farthest sign location from the exit, and

12. K_2 = the position of the sign in the group of multiple signs at a location. For example, if three signs at a location $K_2 = 1$ denotes the left sign; i.e., above the left lane, $K_2 = 2$ denotes the sign at the center and $K_2 = 3$ denotes the right most sign.

Tables 4.18, 4.19, and 4.20 present only the significant and the most important correlation coefficients obtained from the analyses for each of the test routes.

The correlation coefficients between the three basic measures T_{max}, T_f, and T_{used} for each of the sub-test routes are presented in Table 4.18. The data presented in this table gives further support to the findings obtained from studies F-1, F-4, and F-6, that the relationship between T_{max} and T_f and the relationship between T_f and T_{used} is a stable and most basic characteristic of the sign reading behaviors of drivers.

Figures 4.36 and 4.37 present the mean values of T_{used} and T_f, respectively, for the signs on the eight sub-routes. It should be noted that, in general, the values of T_{used} obtained on these sub-routes were higher than those obtained in the previous studies. Further, the values of the measure T_f were smaller, and as a result the drivers had to time-share heavily with the signs in Akron. This finding can be clearly understood by observing the plot of T_{max}/T_f and T_i/T_{used} presented in Figure 4.38. It should be noted that in this figure the

Table 4.18

Correlation of Sign Evaluation Measures

Sub-route Number	MEASURES CORRELATED		
	T_{max} and T_f	T_f and T_{used}	T_{max} and T_{used}
601	0.526	0.663	0.652
602	-	0.902	-
603	-	0.722	-
701	0.647	0.416	0.853
702	0.720	0.805	0.480
703	0.769	0.626	-
801	0.594	0.757	0.512
802	0.497	-	0.573

Note: Only those correlation coefficients (ρ's) which were found to be significant at $\rho < 0.25$ are present in this table.

Hypothesis tested: $H_0: \rho = 0$ vs. $H_1: \rho \neq 0$

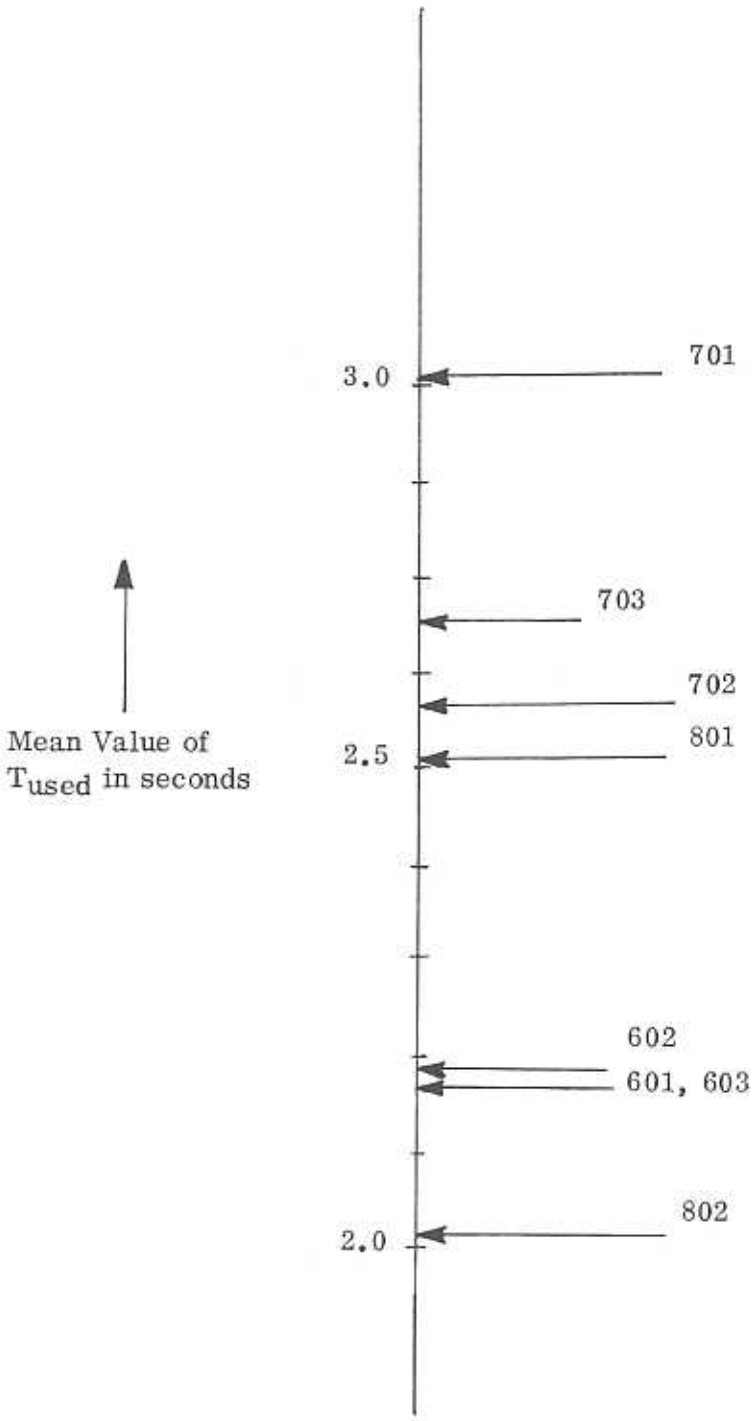


Figure 4.36.--Mean Values of T_{used} Obtained for the Sub-Routes Studied in Akron

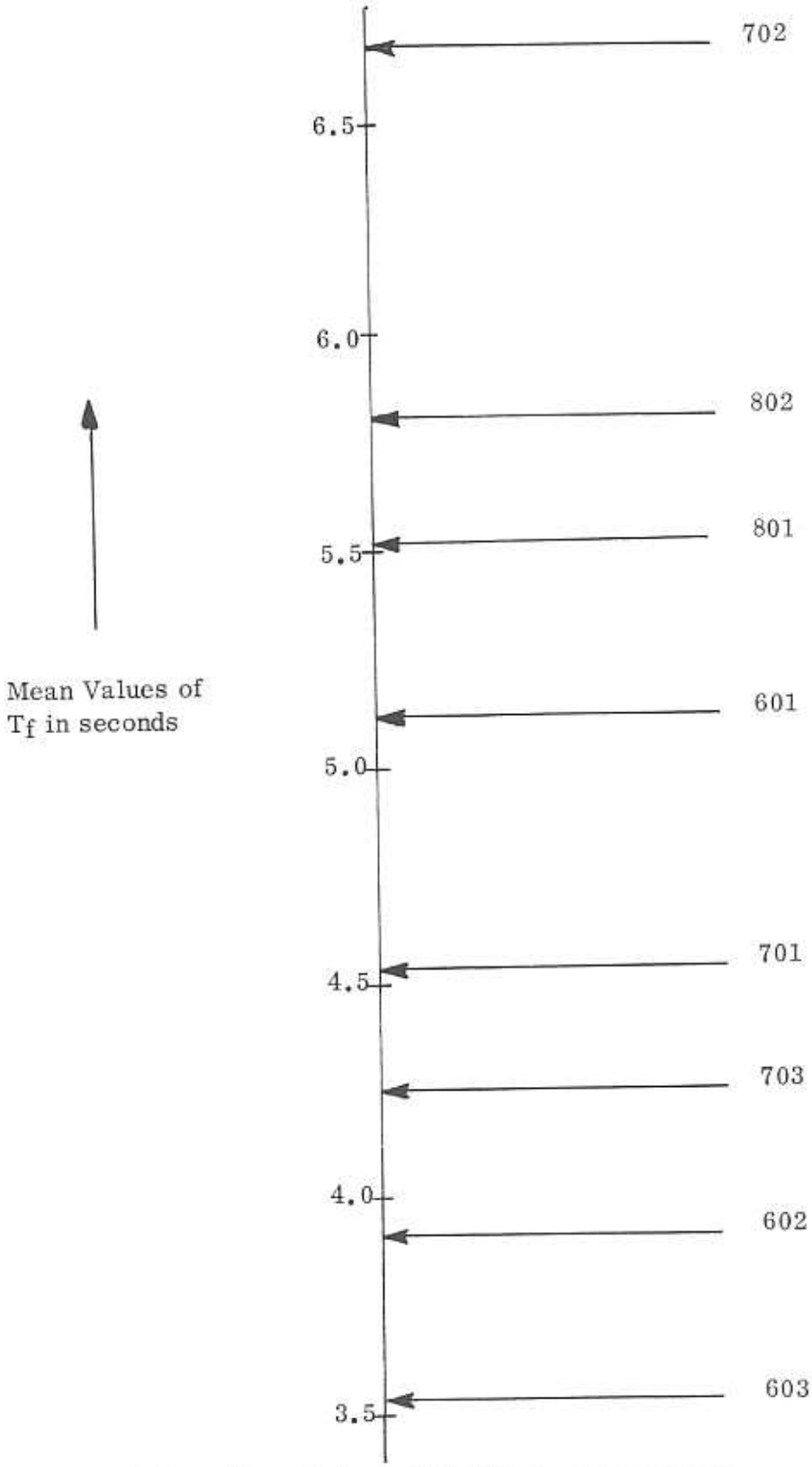


Figure 4.37.--Mean Values of T_f Obtained for the Sub-Routes Studied in Akron

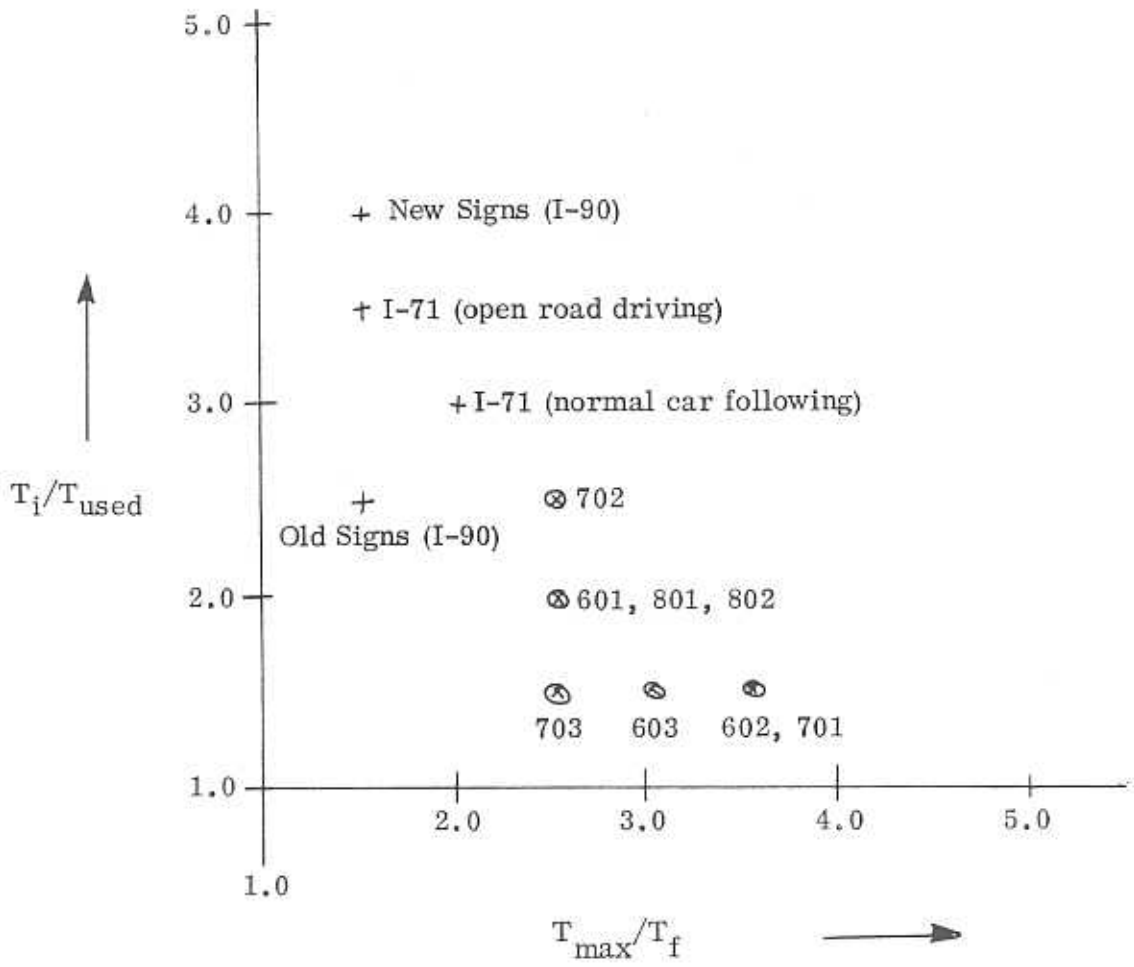


Figure 4.38.--Plot of 50th Percentile Values of T_{max}/T_f and T_i/T_{used} Illustrating Marked Differences Between the Sign Reading Behaviors of the Drivers on the Sub-Routes in Akron and the Data Obtained from Other Studies in this Research Project

Table 4.19

Correlation Coefficients of the Longitudinal Sign Location Number (K_1) with the Sign Evaluation Measures

Sub-Route Number	T_{used}	T_e	T_f	T_{max}/T_{used}	T_{max}/T_i	T_i/T_{used}	T_{max}/T_f
601	-	-	-	0.427	0.618		0.656
602	-	-	-	-	-	0.497	-
603	-	0.421	0.505	-	-	-	-0.568
701	0.831	0.807	-0.473	-0.901	-0.407	-0.682	-0.563
702	0.454	-	-	-	-	-0.353	-
703	-0.324	-	-	0.812	0.566	0.434	0.671
801	0.508	0.316	0.927	-	-0.902	0.411	-0.846
802	-	0.327	-	0.598	-	0.425	-

Note: Only those correlation coefficients (ρ's) which were found to be significant at $p < 0.25$ are presented in this table.

Hypothesis tested: $H_0: \rho = 0$ vs. $H_1: \rho \neq 0$.

Table 4.20

Correlation Coefficients of the Position of the Signs (K_2) with the Sign Evaluation Measures

Sub-Route Number	T_{used}	T_e	T_f	T_{max}/T_{used}	T_{max}/T_i	T_i/T_{used}	T_{max}/T_f
601	-	-	-	-	-	-	-
602	-	-	-	-	-	-	-
603	-	-0.360	-	-	-	-	-
701	-	-	-0.474	-	0.409	-	0.421
702	-	-	-	-	-	-	-
703	-	-	-	-0.395	0.385	-	-0.420
801	-	-	-	-	-	-	-
802	-	-	-	-	-	-	-

Note: Only those correlation coefficients (ρ's) which were found to be significant at $p < 0.25$ are presented in this table.

Hypothesis tested: $H_0: \rho = 0$ vs. $H_1: \rho \neq 0$

50th percentile values of T_{max}/T_f and T_i/T_{used} obtained from other studies conducted in this research project are also plotted. The comparisons of the values presented in Figure 4.38 clearly show that all the sub-routes in Akron lie on the lower right hand side of the plot, and thus, indicating that the subjects while driving in Akron were highly loaded (due to higher values of T_{max}/T_f which were found to be associated due to higher levels of visual loads due to increased traffic density). Further, since all the subjects used in this experiment were totally unfamiliar to the highways, they required higher time to read the signs. The data, therefore, show that the drivers had to concentrate; i.e., time-share heavily, on the signs. It should be noted that the average values of T_{max} for the signs in Akron were 11.7 seconds.

From the correlation coefficients presented in Table 4.19, the following conclusions can be drawn.

1. In sub-routes 701, 702, and 801 the time taken by the subjects to obtain information from the signs increased as the number of sign location increased; i.e., as the driver approached closer to the exit, whereas, the data on sub-route 703 shows opposite driver behavior. It should be noted that the test route 703 involved the most common and standard geometric situation, whereas, sub-routes 701 and 702 involved complex geometric design of the highway.

2. The negative correlation observed between K_1 and T_{max}/T_f for the sub-routes 603, 701, and 801 showed increase in driver urgency as the driver approached closer to the exit. It should be noted that sub-route 603 involved a left hand exit and the sub-route 703 involved a standard right hand exit and the correlations of K_1 with T_{max}/T_f for the two have opposite signs.

3. The positive significant correlation between K_1 and T_i/T_{used} show increase in concentration of the drivers time-sharing process on the sign as the driver approached towards the exit. The above mentioned behavior was observed for sub-routes 602, 703, 801, and 802.

Similarly, a reader is advised to carefully interpret the correlation coefficients presented in Table 4.19 to gain additional insights into the differences in the sign reading behaviors of drivers on the different sub-routes.

Table 4.20 presents the correlation of K_2 with the sign evaluation measures. From this table the following inferences can be drawn.

1. The time spent by the subjects; i.e., T_{used}, was not related to the position of signs at any location; i.e., in general, the drivers tended to use equal time (or there was no statistically significant difference) to signs in all positions.

2. The sub-route 603 involved a left hand exit and the negative correlation of T_e with K_2 and the positive correlation between T_{max}/T_f and K_2 suggest that the drivers primarily attend the signs on the left side first and then obtain information from the signs on the right.

3. The sub-test route 703 involved a standard right hand exit and negative significant correlation of K_2 with T_{max}/T_f indicates that the values of T_{max}/T_f were smaller for the signs on the right side; i.e., the signs that presented information pertaining to the route.

The discussions presented above on the basis of the observed correlations among different measures illustrate some differences among the sub-routes; but these discussions primarily illustrate the influence of the signing and road geometric characteristics on the sign reading behaviors of drivers only at a macroscopic level. Therefore, further analyses were performed at a microscopic level; i.e., observing each successive fixation that a driver makes as he approaches a sign location.

The test sub-routes 601 and 701 were found to be the most difficult routes for the test drivers to follow. On the sub-route 601, out of the five subjects tested, one entirely missed the right hand turn to continue on I-80 S (East) and two subjects changed lanes abruptly just prior to the gore area. The other two subjects completed the maneuver satisfactorily. Similarly, on sub-route 701, two out of the five subjects made abrupt lane changes and cut through the gore areas in order to continue on I-80 S (West) at the interchange B.

Obviously, the geometric design of the highway led the unfamiliar drivers in making late manuvers (or missing the routes). When the fixations made by the drivers who responded late were analyzed along with the consideration of the sign evaluation measures for each of the signs on the route, the following important effects were observed.

1. In case of multiple signs at a location an approaching driver (who wants to continue on the same interstate highways) generally appears to have a natural tendency to read the left-most signs first. Thus, when our test drivers were asked to follow I-80 S (East) in sub-route 701, being

unfamiliar with the geometric situation assumed the interstate highway to be continued straight ahead and read the left most signs first. Further, since the values of T_f were smaller, it is found that while approaching the multiple signs under such situations; i.e., when a major interstate highway turns in a different direction from the mainstream, the drivers only had enough time to read the signs of the left and they either missed the signs mounted on the right side (at first few locations) or did not have enough time to read the signs on the right side which provided information pertaining to their intended route.

2. The above mentioned behavior was most pronounced for the signs at the last location; i.e., signing just prior to diverging road geometry, and if the test driver under such conditions was in the wrong lane he usually made abrupt lane changes and cut across the gore area to follow the correct route.

3. The drivers on the above discussed conditions were found to be spending on the average about 2.68 seconds (range: 1.43 to 4.31 seconds) and 1.85 seconds (range: 0.93 to 2.62 seconds) for the left-most and the right-most signs (at a location), respectively.

Study F-8

Title: A Study of Signs of Special Interest

Objectives: The primary objective of this study was to investigate the sign reading behaviors of drivers and to apply the sign evaluation methodology to attempt to determine causes that contribute towards some special aspects that are associated with the signing at some selected locations.

The locations selected for this study had the following special characteristics:

1. diagrammatic signing,

2. locations at which the signing is generally regarded as "confusing" (or inadequate), and

3. special lane change signs located upstream to merging areas.

DESCRIPTION OF THE STUDY

This study consisted of the evaluation of signing at five different locations. At the five locations the driver eye movements and the driving performance data for two to five subjects was collected. The details concerning the locations of the test routes, the subject instructions and the category of signing of interest considered in this study are summarized in Table 4.21. The details of the signing, the experimental procedure, and the results for each of the test routes are discussed in the following pages.

Test Route 401

The aim of the testing on this test route was to evaluate a newly mounted diagrammatic sign on I-70. Figure 4.39 gives a pictorial view of this diagrammatic sign.

Five subjects were used for this experiment and the data on the driver eye movements and the driving performance was collected on this test route in a car-following mode. A lead car and the experimental vehicle were driven on I-70 westbound from an entrance located at about 3 miles upstream of the diagrammatic sign. While car following, the subject was casually given the following instructions.

> "We want to calibrate the eye-marker system so, we want you to follow the lead vehicle at about 125 feet and constantly stare at the lead car. We want you to perform this task until you come to State Route 79. Then, we want you to exit at State Route 79 (South). The experimenter in the lead car will be going back to the university, but we will be conducting additional experiments on State Route 79 (South), but do not forget to stare at the lead car as much as you can and maintain 125 feet distance."

After these instructions, the eye-marker camera and the oscillograph recorder were turned on to collect data as the driver approached the seven signs on the test route. The description of the sequence of signs in this experiment is presented in Appendix A.

Tables 4.22 and 4.23 present the results obtained from the analysis of the collected data by using the computer program SEADEM II. The important results obtained from this experiment are as follows.

1. The subjects on the average spent 6.65 seconds obtaining information from the diagrammatic sign.

Table 4.21

Details of Signing of Special Interest

Test Route No.	Location	Highway	Abstract of Driver Instructions	Category of Signing of Interest
401	Hebron	I-70 (West)	While traveling west on I-70 exit at SR 79 (South)	Diagrammatic Sign
501	Columbus	SR 33 (SE) and I-71 (North)	Enter SR 33 (SE) and get on I-71 (North)	Confusing
502	Columbus	SR 33 (SE) and I-71 (South)	Enter SR 33 (SE) and get on I-71 (South)	Confusing
503	Columbus	I-71 (South) and I-270 (East)	Enter I-71 (South) at Frank Road and then get on I-270 (East)	Study of lane change signs vs. road markings at merging
504	Columbus	I-270 (East)	Enter I-270 (East) at Grove City entrance and continue on I-270 (East)	Study of lane change signs vs. road markings at merging

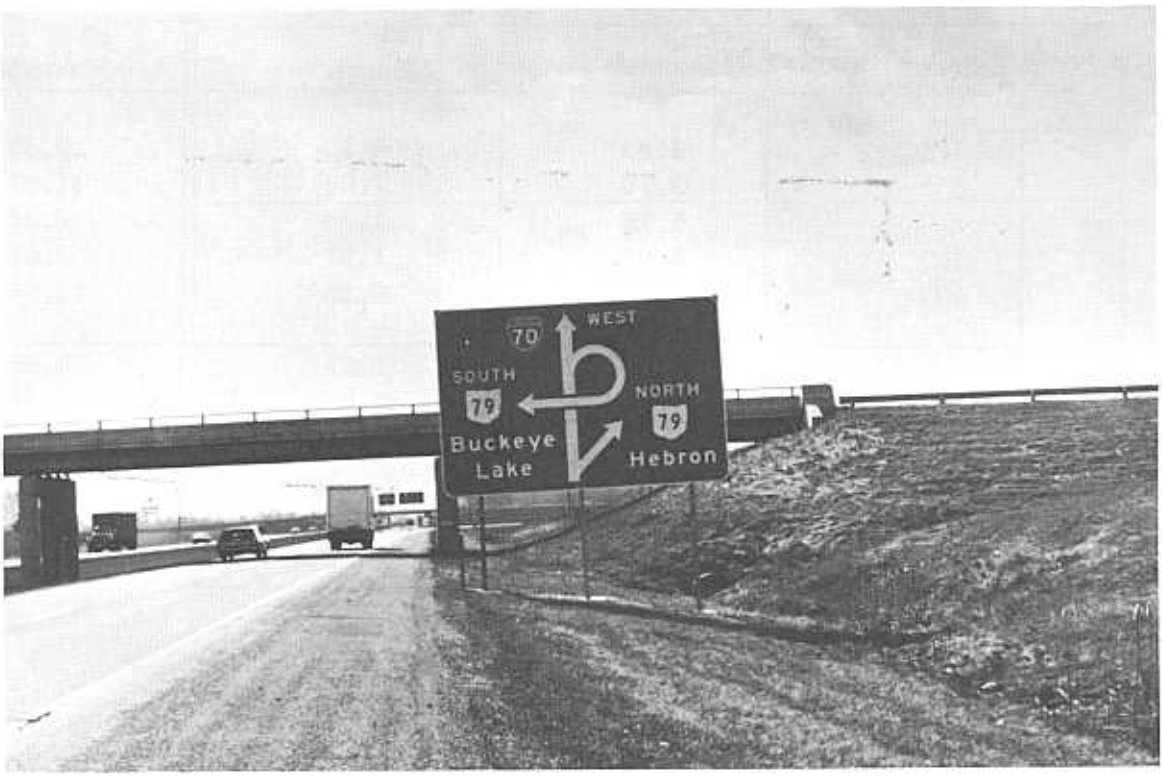


Figure 4.39.--The diagrammatic sign on I-70

Table 4.22

Values of the Measures T_{used}, T_e and T_f obtained for the Diagrammatic Sign

Subject	T_{used} in Seconds	T_e in Seconds	T_f in Seconds
HU	4.82	4.25	10.30
FS	9.70	1.94	11.81
GO	5.19	1.20	8.37
HO	6.80	1.87	8.68
EN	6.75	3.25	10.58
Mean values by aggregating the data for five subjects	6.65	2.50	9.95

Table 4.23

Comparison of the Mean Values of the Measures for the Diagrammatic Sign with the other Non-diagrammatic Signs on the Test Route

Measure	Diagrammatic Sign	Nondiagrammatic (All signs on the route except the diagrammatic sign)
T_{used}	6.65	1.762
T_e	2.50	0.800
T_f	9.95	3.13
T_i/T_{used}	1.148	1.585
T_{max}/T_f	1.180	3.439

2. The values of measures T_i and T_{used} for the diagrammatic sign were very high as compared to the other non-diagrammatic signs on the test route. Also, the values of T_i/T_{used} were very close to 1.0. (Note: Under normal driving situations and standard signing the values of T_i/T_{used} average in the range of 3.0 to 4.0.)

3. Both the above findings suggest that the drivers had to spend large amounts of time and concentrate heavily (i.e., very little time-sharing with the other objects in the driver's view was exhibited by the driver's between T_f and T_e) on the diagrammatic sign. Both the above findings, thus, suggest that the message displayed on the sign was difficult to comprehend as compared to the standard symbolic highway signs.

4. It should be noted that since the diagrammatic sign studied was the only example of the diagrammatic sign in the vicinity of the Columbus area, there may be an influence on the sign reading behaviors of the drivers due to the effect of the novelty and this is suggested by very low values of T_{max}/T_f. Further, it should be noted that low values of T_{max}/T_f also suggest very high sign detection capability; i.e., the target value, of this diagrammatic sign.

Test Routes 501 and 502

For the purpose of this experiment a list of various different locations in the Columbus area which were "commonly" considered as very confusing were made by interviewing many researchers in our group and also the local officials of the Ohio Department of Highways. After the discussions it was felt that the signs encountered by the drivers while approaching I-71 from State Route 33 (Southeast) were good examples of confusing signing (see Figure 4.40). Therefore, the eye movements and driving performance data for three subjects was collected while getting on I-71 in both directions from State Route 33 (Southeast). In these data collection runs, no lead car was used and the following instructions were given to the subjects while driving and when they were about 1-1/4 miles upstream of I-71 on State Route 33 (Southeast).

Test Route 501

"Now we would like you to continue driving in your normal manner and get on I-71 heading north."

After the subject completed this run, he was guided by the experimenter back on State Route 33 heading southeast and the following instructions were given when he was about 1-1/4 miles upstream of I-71.

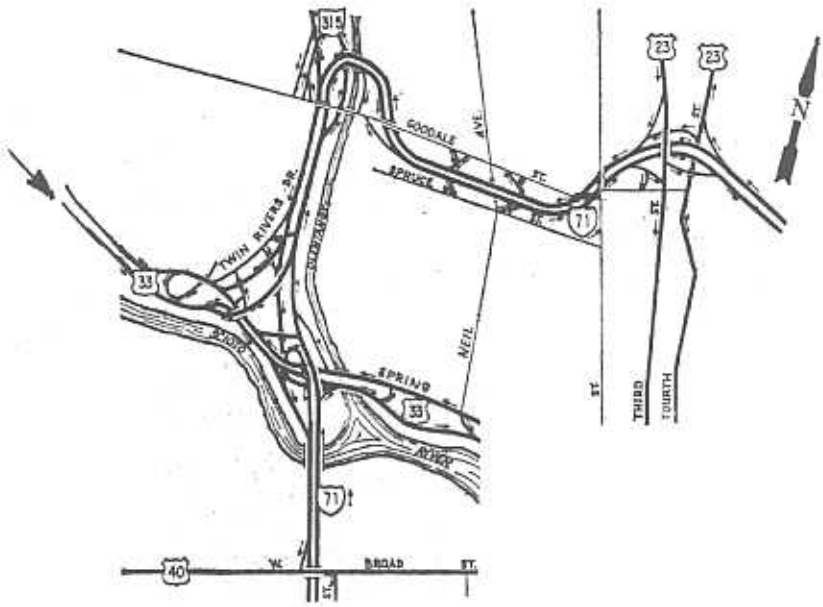


Figure 4.40.--Map Showing the Intersection of SR 33 and I-71

Test Route 502

"Now we would like you to continue driving in your normal manner and get on I-71 heading south."

From the map of the test area presented in Figure 4.40, it is clear that as the driver approached I-71 from State Route 33 (Southeast) there were two roads, namely, Twin Rivers Drive and Long Street, diverging from State Route 33 and the side-mounted signs indicating the diverging roads were small and were mounted in the gore areas of the diverging roads. Tables 4.24 and 4.25 present some illustrative data and the sketches of the signs on the test routes 501 and 502, respectively.

The data obtained from these runs primarily indicate that the signs on the route did not give sufficient time to the drivers to obtain the necessary information. The results of the studies F-5, L-2, and L-3 have indicated that in order to read the messages presented in two lines and in 5 to 6 words, the drivers would require about 2.0 seconds.

In both the test routes the first sign provided adequate time to the drivers to obtain the information but the later signs provided very little time to read and select the required path. The illustrative data for the two subjects presented in Table 4.25 shows that by the time the subjects completed reading the overhead-mounted sign at the third location that provided the information to get on I-71 (South), they were about 1/2 second upstream of the sign and this sign was mounted in the gore area. As a result, two out of the three subjects tested on this test route (i.e., 502) could not get on I-71 and continued driving on Long Street.

Test Routes 503 and 504

During informal discussions with the local officials of the Ohio Department of Highways, a question was raised regarding the use of special lane change signs. In order to gain some insight into the understanding on how the drivers obtain information from the lane change signs a small exploratory study was conducted at the I-71 - I-270 interchange on the south side of Columbus (see Figure 4.41).

At this interchange the traffic approaching from both the north and south directions of I-71 merges into the eastbound traffic on I-270 and in spite of the two lane change signs and the cross stripping on the lanes (see Figure 4.41), it is observed that the drivers do not change lanes as desired.

Table 4.24

Illustration of the Data Obtained for Subject "GO" on the Test Route 501

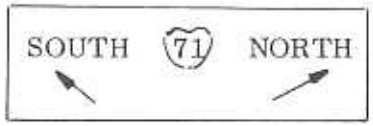
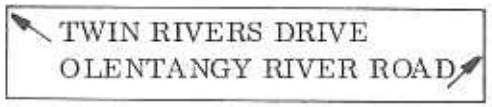
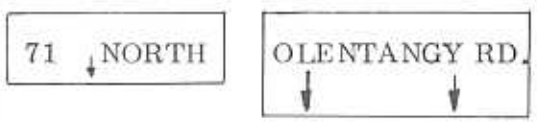
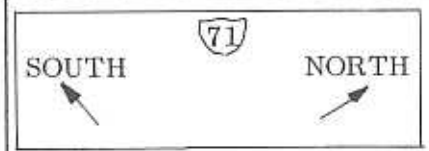
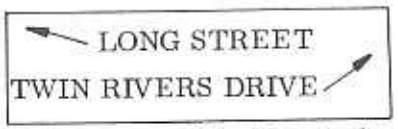
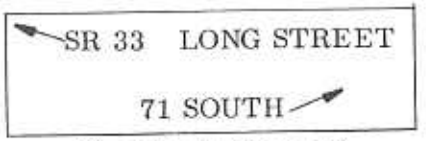
Location of the sign in the sequence	Sketch of the Sign	T_{max}	T_{used}	T_e	T_f	T_i/T_{used}	T_{max}/T_f
1	 (Side Mounted: Right)	9.05	2.31	0.56	4.43	1.7	2.0
2	 (Side Mounted: Left)	5.50	0.88	1.06	1.93	1.0	2.8
3	 (Side Mounted: Right)	12.12	1.43	0.40	5.68	3.7	2.1
5		13.43 13.43	0.56 1.00	0.87 0.87	1.43 2.37	1.0 1.5	9.3 5.7

Table 4.25

Illustration of the Data Obtained for Two Subjects on Test Route 502

Location of the Sign in Sequence	1		2		3	
Sketch of the Sign	 (Side Mounted)		 (Side Mounted)		 (Overhead Mounted)	
Subject Measure	HU	GO	HU	GO	HU	GO
T_{max}	8.922	10.511	5.875	5.625	13.687	12.812
T_{used}	2.375	3.125	1.250	0.937	2.375	2.187
T_e	0.750	0.812	0.875	0.875	0.625	0.437
T_f	3.437	5.250	2.125	1.812	4.500	4.312
T_i/T_{used}	1.1	1.4	1.0	1.0	1.60	1.8
T_{max}/T_f	2.6	2.0	2.8	3.1	3.0	3.0
Comments					The subject was in the wrong lane while reading this sign and did not enter I-71.	The subject was in the correct lane and entered I-71 (South)

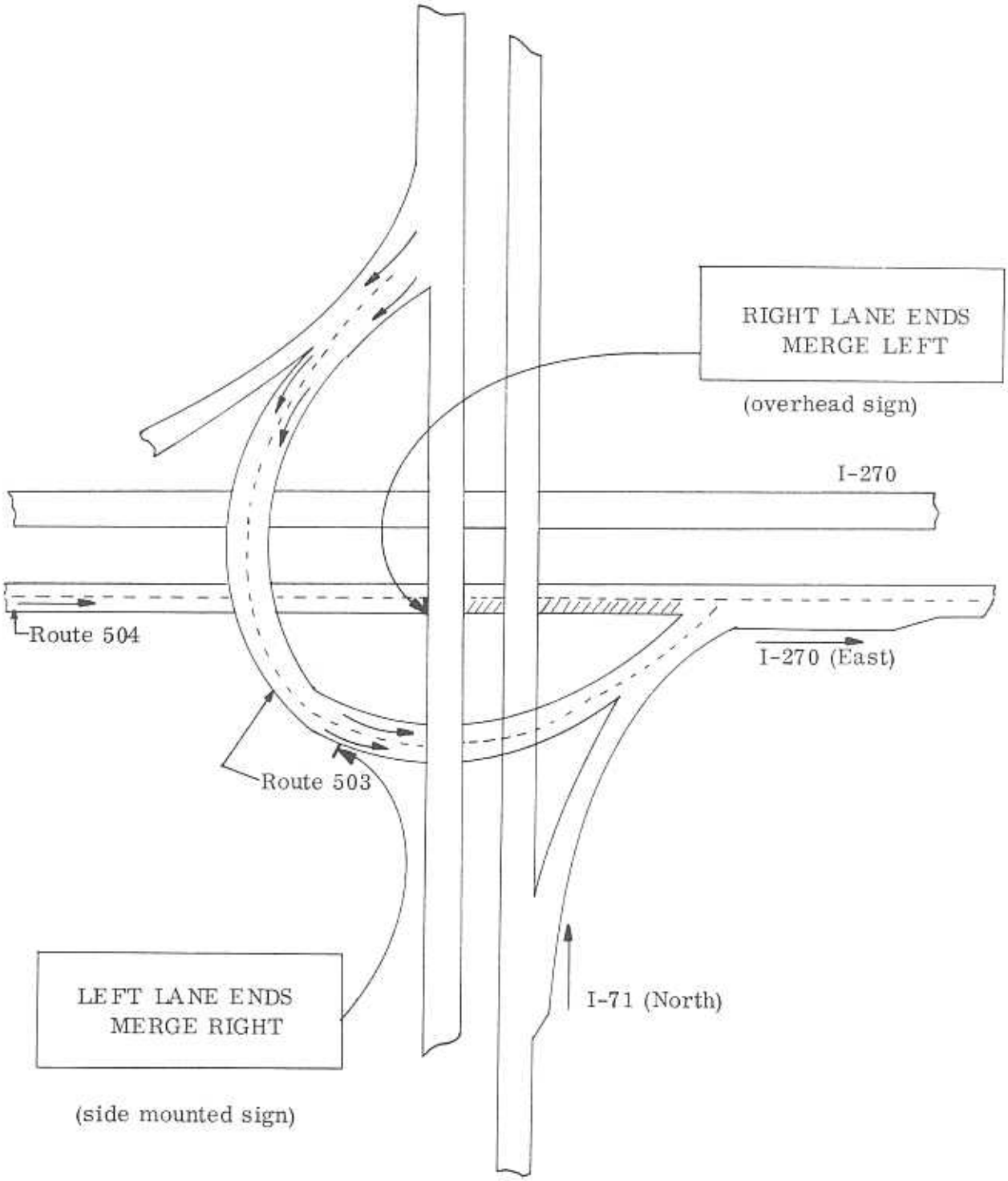


Figure 4.41.--Schematic Diagram of I-71 and I-270 Interchange Showing the Configuration of Only the Important Ramps, the Cross Stripping Used to Force Lane Changes and the Location of the Two Lane Change Signs

In order to get some exploratory data on the sign reading behaviors of drivers on the two lane change signs the data was collected for two subjects using two test routes. The instructions presented to the subjects were as follows.

Test Route 503

While the subject was traveling southbound on I-71 about a mile upstream of the interchange, the following instructions were presented to the subject.

> "Now we want to get on I-270 heading east. So, please drive in your normal manner and exit at the junction of I-71 - I-270 and follow I-270 (East). During this run, if you desire to change lanes then let us know and we will tell you when it is safe to do so."

Test Route 504

At the entrance ramp on I-270 (East) at Harrisburg Pike (i.e., U. S. 62) the subject was given the following instructions.

> "We would like you to enter the freeway and continue driving in the right lane in your normal manner in I-270 (East) until we give further instructions. If due to some reason you need to change the lane, please let us know and we will tell you when it is safe to do so."

Table 4.26 summarizes the results obtained from the four test runs conducted in this experiment. The results show that in two out of the four cases the subjects did respond to the lane change signs. In one of the runs, namely, of subject HU on test route 504, our data indicated that the subject did read the sign but did not change lanes. The results, thus, suggest that the driver behavior in lane changes is much more complex and merely the placement of the lane change signs is not adequate to solve the problem. This is especially true in a situation such as in test route 504 where our approaching driver can clearly see at a distance that the lane continues on, in spite of the lane change sign and the stripping on the pavement.

Table 4.26

Summary of Observed Behavior of the Test Subjects
in Responding to Lane Change Signs

	Test Route			
	503		504	
Subject	GO	HU	GO	HU
Details				
Was the subject driving in the correct lane prior to approaching the lane change sign?	YES	NO	NO	NO
Did the subject read lane change sign?	NO	YES	YES	YES
Did the subject change lanes?	(Not applicable)	YES	YES	NO
T_{used}		0.500	0.500	1.000
T_e		1.0625	3.810	1.935
T_f		2.6250	4.310	3.200

Study L-1

Title: A Laboratory Study for the Investigation of T_{reqd} by Tachistoscopic* Presentation of Signs

Objectives: This experiment was conducted as a pilot study to gain more understanding for the development of the measure, T_{reqd}. The aim of this experiment was to investigate the effect of the following factors in the determination of T_{reqd},

1. length of message on a sign, and
2. familiarity of the subject with the message presented on a sign.

DESCRIPTION OF THE EXPERIMENT

In this experiment color slides of 32 different interstate highway signs were tachistoscopically presented to nine subjects. All nine subjects were undergraduate students in the Industrial Engineering Department of The Ohio State University. The signs were presented to the subjects in tachistoscopic exposures of 10 msec. duration, and the subjects were given advance warning before presenting each flash to make sure that their eyes were fixated on the screen. The subjects were allowed to fixate anywhere on the screen in the experiment. The number of flashed required to recite the message presented on a sign was considered as a response (dependent) variable. The 32 signs were selected so that four different levels of length of message could be tested. The criterion used to determine the length of message was the number of lines of message on a sign. Eight signs displaying approximately the same type of message were selected for each level. The eight signs in each of the levels, 1, 2, 3, and 4, constituted signs which displayed messages in 1, 2, 3, and 4 lines of message, respectively. The 32 slides were randomly arranged on the slide tray of the tachistoscope, and the experiment was replicated three times in the same random sequence to get the effect of familiarity. For more details on the experiment the interested reader is referred to the interim report of this project.

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*A tachistoscope is an apparatus for exposing visual stimuli to the test subjects for very short durations (of the order of fractions of a second). The tachistoscope used in this experiment consisted of a Kodak Carousel slide projector equipped with a shutter in front of its lens. The shutter had the capability of exposing (or flashing) slides of signs for durations ranging between 1/1000th of a second to 1 second.

Results

The data obtained from this experiment was analyzed by using a three factor analysis of variance model in which the three factors were:

1. familiarity of the subject with a sign,

2. length of message, and

3. subjects.

The results of the ANOVA were as follows:

1. both the linear and the quadratic components of the effect due to the length of message were significant at 0.001 level,

2. both the linear and the quadratic components of the effect due to familiarity were significant at 0.001 level,

3. the effect due to subjects was significant at 0.005 level, and

4. the effect due to interaction between subjects and length of message was significant at 0.025 level.

Figure 4.42 shows the relationship of the number of flashed of 10 msec. exposure to the number of lines and familiarity.

Study L-2

Title: A Laboratory Study for the Determination of T_{reqd} by Using a Laboratory Eye-Movement Recorder

Objectives: This experiment was primarily conducted for the following two reasons.

1. In study F-5, the driver eye-movement data was collected to obtain the effects of different variables (such as length of message, type of informational need, etc.) on the minimum time (T_{reqd}) required to obtain necessary information from a sign. The experimental procedure and the setup required to collect the data in study F-5 was time consuming and expensive.

   Further, the results obtained from the study L-1 and F-5 could not be directly compared because of differences in

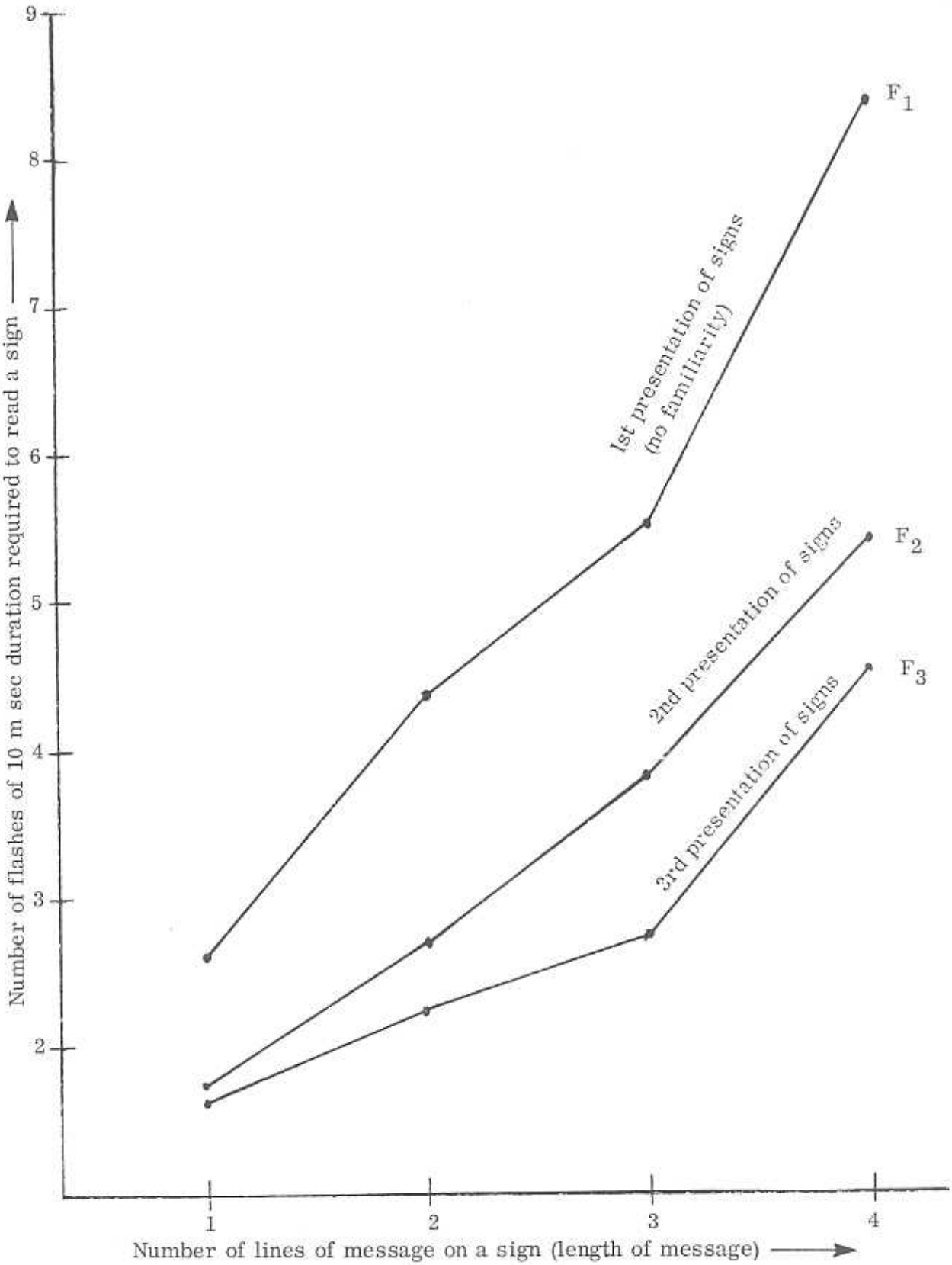


Figure 4.42.--Number of Tachistoscopic Exposures Graphed as a Function of the Number of Lines of Message and Familiarity

experimental conditions and due to differences in the unit of measurement of T_{reqd}. This experiment was, therefore, conducted to determine if comparable results on T_{reqd} could be obtained in a relatively less expensive way by devising a laboratory setup.

2. The findings of the study F-5 suggest that T_{reqd} was a function of line position of the required information in the displayed message on the sign and since additional road experiments could not be conducted, it was decided to study this additional variable; i.e., the effect of position of required information in this experiment.

This experiment was, therefore, designed to investigate the effects of the following independent variables on T_{reqd}:

1. length of message,
   a. number of lines (two levels, 2L and 4L), and
   b. number of words in a line (two levels, 1W and 2W),
2. familiarity of the message to the subject (two levels, F1 and F2),
3. type of informational need (IN) (three levels, IN 1, IN 2, and IN 3, defined similar to those in the study F-5), and
4. line position of needed information in the displayed information (two or four levels depending upon if the message length was 2L or 4L). (Note: The four positions are defined as P1, P2, P3, and P4.)

DESCRIPTION OF THE EXPERIMENT

In this experiment, slides of signs were shown to the subjects on a screen and the time required for the subjects to obtain required information from the sign was recorded. The equipment setup used for this experiment is illustrated in Figure 4.43. The eye movements of subjects were monitored by a laboratory eye-movement monitor, Biometrics, Model SUHV/2. The output of the eye-movement monitor was fed into a PDP-8 computer which was programmed to compute the time spent by the subjects in reading the signs projected on the screen. The measurement of the time required by the subjects to obtain the required information from a sign was accomplished by using the following procedure.

As shown in the Figure 4.43, the subject sat at a longitudinal distance 'd' from the screen. The projector was located to the right of the subject such that the center of the slide (i.e., the point 'x' subtended an angle ϕ_o and the sign subtended an angle β) at the cyclopean eye position of the subject.

Two subjects, namely, subject KF and DF, participated in this experiment. Both these subjects had participated in the study F-5. In study F-5, the subjects had to drive in the left lane and obtain information from a programmable sign mounted on the right side of the road. The subjects in study F-5 were instructed to look at the sign when they approached a preselected distance (refer to subject instructions in study F-5). In order to obtain comparable geometric configuration, the angles ϕ_o and β in this experiment were selected by studying the data obtained for each of the two subjects from the study F-5 (i.e., when the subjects in that study F-5 started looking at the programmable sign).

In this experiment before presenting a sign, the subject was first asked to fixate at the calibration point. At that instance, the PDP-8 computer sampled the horizontal coordinate of the calibration point. The subject was then asked to fixate on point "zero" on the screen and then the shutter in front of the lens of the slide projector was opened by the experimenter. As soon as the shutter was open the subject was instructed to move his eyes towards the sign to obtain required information and was also asked to move his eyes to the left and fixate on point "zero" as soon as he finished reading. The PDP-8 computer determined the time during which the subject's eyes were directed to the right of the calibration point, and this measured time was printed on the printer after the trial was over.

Thus, for each trial the experimenter's task consisted of the operations in the following sequence:

1. present question to the subject, (the questions were different depending upon the presented slide and the type of informational need)

2. alert PDP-8 computer,

3. ask subject to look at calibration point for one second,

4. ask subject to look at the "zero" point,

5. push shutter opening switch, (the subject then immediately moved his eyes past the calibration point to obtain information necessary from the sign and was asked to fixate on point "zero" as soon as he received the information and verbally reported the "answer")

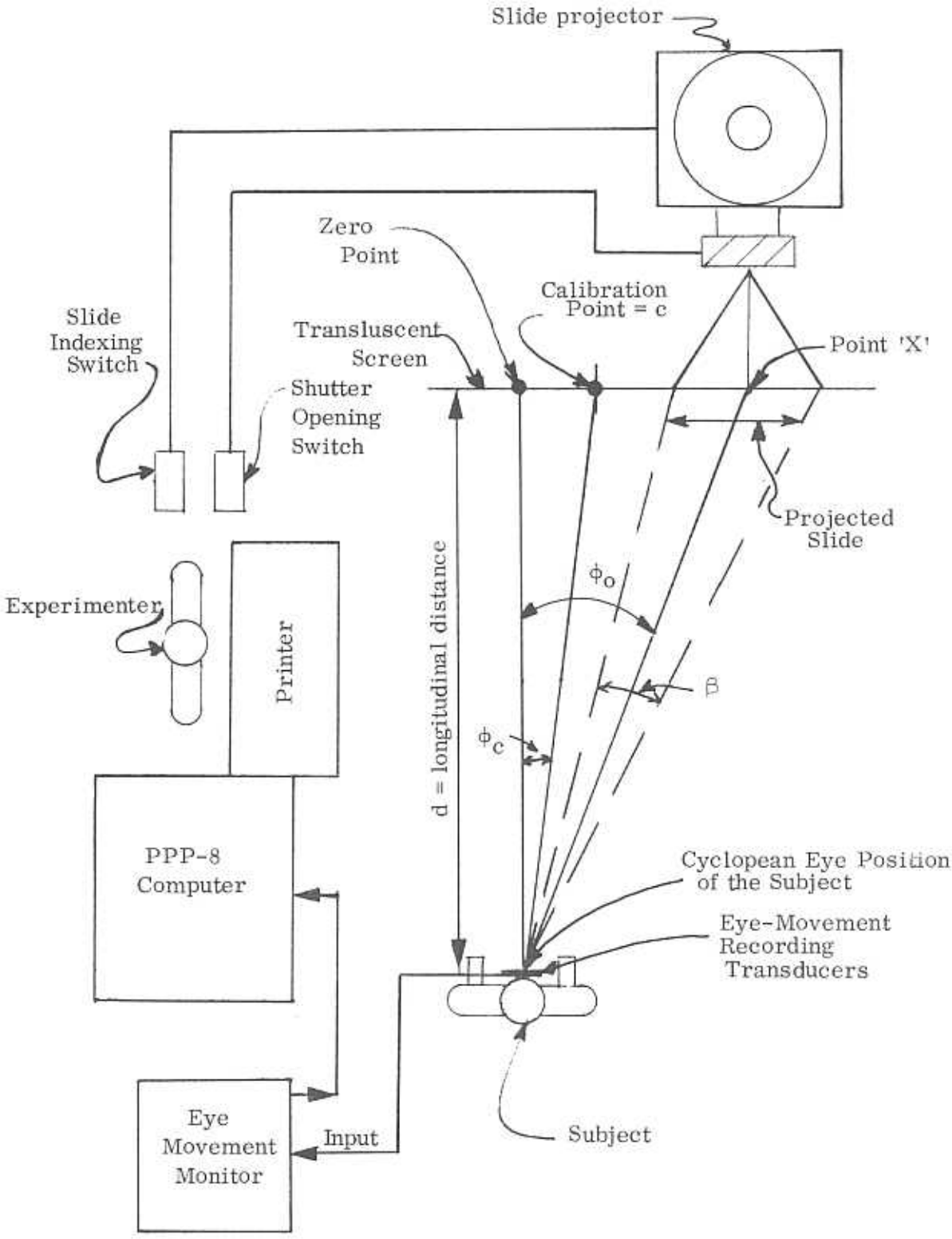


Figure 4.43.--Schematic Sketch of the Plan View of the Experimental Setup in Study L-2

6. close shutter,

7. record subject's answer,

8. index to the next slide, and

9. ask question for next trial and repeat steps (1) through (8) for the next trial.

Each subject went through two experimental sessions consisting of 108 trials. The two experimental sessions of each subject were conducted at the interval of two days and in each of the sessions the same 108 trials were conducted. The first session, thus, gave data under conditions of F1 (i.e., no familiarity) and the data collected in the second experimental session represented F2 condition.

The 108 trials consisted of presentation of three identical sets of thirty-six slides. The messages presented on the thirty-six slides are presented in Table 4.27. Figure 4.44 presents examples of the slides (slide numbers 34 and 5 in Table 4.27). These slides presented the messages in white letters on standard green background. It should be noted that the messages presented on these slides were similar to those used in the study F-5. The 108 slides were randomly ordered and the questions asked to the subjects for each of the trials were arranged so that the experiment design presented in Table 4.28 was mapped.

The trials of type IN 1 and IN 2 required the subject to obtain the information that was a part of the total message presented by the slides, whereas, in trials of type IN 3 the required information was not presented on the signs. Therefore, for conditions of IN 1 and IN 2 the effect of position of the required message (i.e., the number of lines in which the required information was presented) could be investigated. It should be noted that in the case of the signs that presented the messages in two lines, the two lines were centered on the slides such that they appeared in the positions of lines 2 and 3 when compared with signs with 4 line messages.

Subject Instructions

Prior to each data collection session the subjects were given the following instructions.

> "In this experiment we want to find out the minimum time that you will need to obtain information to answer the question presented to you prior to presentation of

Table 4.27

Messages Presented in the Set of Thirty-Six Slides

Slide No.	Message presented by the slide	Slide No.	Message presented by the slide
1	Rockwell Research 17 Frantiz Road 18 Science Center 36 Bremen Plaza 28	2	Traffic Solution 22 Francis Terrace 18 Sunshine Park 38 Conoid Avenue 39
3	Golden Island 32 Bishof Drive 23 Human Factors 41 Cosine South 29	4	Biretta Street 25 Summer Theater 34 Colony North 92 Ronnie Farm 43
5	Bremen Plaza 28 Science Center 36 Sunset Grove 26 Walnut Creek 45	6	Frantiz Road 81 Sunshine Park 38 Conoid Avenue 39 Rockwell Research 17
7	Traffic Solution 22 Cosine South 29 Human Factors 41 Francis Terrace 18	8	Golden Island 32 Colony North 92 Ronnie Farm 43 Bishof Drive 23
9	Summer Theater 34 Biretta Street 25 Walnut Creek 45 Sunset Grove 26	10	Rockwell Research 17 Summer Theater 34 Human Factors 41 Frantiz Road 81
11	Traffic Solution 22 Science Center 36 Ronnie Farm 43 Bishof Drive 23	12	Golden Island 32 Sunshine Park 38 Walnut Creek 45 Bremen Plaza 28
13	Francis Terrace 18 Frantiz Road 81	14	Biretta Street 25 Rockwell Research 17
15	Conoid Avenue 39 Traffic Solution 22	16	Colony North 92 Cosine South 29
17	Golden Island 32 Colony North 92	18	Summer Theater 34 Sunset Grove 26

Table 4.27 (continued)

Slide No.	Message presented by the slide	Slide No.	Message presented by the slide
19	Martin 15 Tremont 19 Trabue 35 Wesket 30	20	Morris 21 Summit 19 Travis 37 Weldon 51
21	Monroe 31 Dexter 21 Tuttle 40 Swisher 83	22	Carter 27 Mohawk 33 Funstock 64 Astral 42
23	Wesket 30 Trabue 35 Fondorf 46 Bethel 44	24	Tremont 16 Travis 37 Weldon 51 Martin 24
25	Morris 21 Summit 19 Tuttle 40 Swisher 83	26	Monroe 31 Dexter 20 Astral 42 Funstock 64
27	Mohawk 23 Carter 27 Bethel 44 Fondorf 46	28	Martin 28 Mohawk 33 Tuttle 46 Tremont 16
29	Morris 15 Trabue 35 Astral 42 Summit 19	30	Monroe 30 Travis 37 Bethel 44 Dexter 20
31	Carter 27 Tremont 16	32	Wesket 30 Weldon 51
33	Weldon 51 Astral 42	34	Summit 19 Swisher 83
35	Mohawk 33 Funstock 64	36	Funstock 64 Fondorf 46

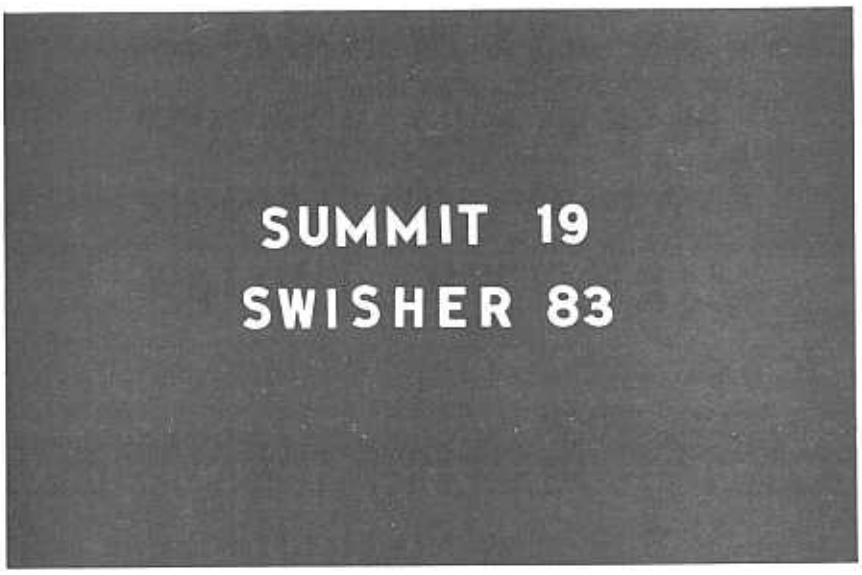


Figure 4.44.--Illustrations of slides presented to the subjects in the Study L-2

each slide of a sign. Your task, therefore, is to look at the slide as soon as it is presented. After obtaining the information necessary to answer the question, we want you to immediately look at the point "zero" and report the answer. Remember that it is very important that you do not look at the sign more than absolute minimum time needed to obtain the answer to the questions. So, try to look at the "zero" point as soon as you get the needed information."

After these instructions, the subject was given some practice runs (these did not use any of the 36 slides used for data collection) until the experimenter was satisfied over the subjects understanding of his task. After this, the data collection session began and before each of the trials, depending upon the trial condition, one of the three questions was presented to the subject.

Type of Informational Need	Question
IN 1	How many miles is "____ x ____"?
IN 2	Does this sign include the words "_x_"?
IN 3	Does this sign include the words "_y_"?

Note: x = represents the word (or words) that was presented in one of the lines on the displayed sign, and

y = represents the word (or words) that were not presented on the displayed sign.

Results

The data obtained in this experiment was analyzed by considering three separate problems. The fixed factor analysis of variance model was used on the three problems. The dependent variable considered for all the problems was T_{reqd}; i.e., the minimum time necessary to acquire the required information from the sign. The factors and their levels considered in the three problems are presented in Table 4.29.

Table 4.30 presents a summary of the results obtained from the three separate problems. The results show that the following main factors, F, IN, and L, were statistically significant. The factor W (i.e., the words per line) was not found to be significant in problems A and B, but in problem C was found to be significant at 0.10 level.

Table 4.28

Experiment Design Showing Number of Replications Used for the Combinations of the Five Factors

		2L				4L			
		1W + N		2W + N		1W + N		2W + N	
		F1	F2	F1	F2	F1	F2	F1	F2
IN1	P1					3	3	3	3
	P2	3	3	3	3	3	3	3	3
	P3	3	3	3	3	3	3	3	3
	P4					3	3	3	3
IN2	P1					3	3	3	3
	P2	3	3	3	3	3	3	3	3
	P3	3	3	3	3	3	3	3	3
	P4					3	3	3	3
IN3		6	6	6	6	12	12	12	12

Table 4.29

Summary of Experiment Designs Considered for the Definition of the Three Problems for the Analysis of Data

Problem	Replications	Factors	Levels
A	6	Subjects Familiarity Words Lines Informational Need	2 3 2 2 3
B (signs involving two line messages in conditions IN1 and IN2)	6	Subjects Familiarity Words Positions	2 2 2 2
C (signs involving four line messages in conditions IN1 and IN2)	6	Subjects Familiarity Words Positions	2 2 2 4

Table 4.30

Results of the ANOVA Tests

Effect due to:*	Significance Levels*		
	Problem A	Problem B (2 line messages)	Problem (4 line messages)
Subjects (S)	NS	p<0.100	NS
Familiarity (F)	p<0.001	p<0.050	p<0.001
Informational Need (IN)	p<0.001	NA	NA
Words (W)	NS	NS	p<0.100
Lines (L)	p<0.001	NA	NA
Position (P)	NA	p<0.25	p<0.001
S x F	p<0.001	NS	p<0.050
S x L	p<0.025	NA	NA
W x IN	p<0.25	NA	NA
L x IN	p<0.010	NA	NA
S x F x L	p<0.100	NA	NA
S x W x IN	p<0.025	NA	NA
F x L x IN	p<0.250	NA	NA
S x P	NA	p<0.100	p<0.100
F x P	NA	NS	p<0.250
W x P	NA	NS	p<0.250
S x F x W	NS	NS	p<0.100

* = Note: 1. Notation NS = not significant
NA = not applicable; i.e., tested design did not include the effect

2. Only the significant interactions are presented in this table.

Figure 4.45 presents the marginal means of T_{reqd} obtained for the four variables in problem A. Figure 4.46, similarly, presents the marginal means of T_{reqd} as a function of position (i.e., number of line) of the needed information in the displayed message. Thus, from the results presented in Table 4.30, Figure 4.45, and Figure 4.46, the following conclusions can be drawn.

Conclusions

1. T_{reqd} the minimum time necessary to acquire required information is significantly affected by familiarity of the subjects with the messages presented as the signs.

2. T_{reqd} increases with increase in length of message; i.e., lines and words per line displayed on the signs. The effect of number of lines of displayed message on T_{reqd} is more pronounced than the effect of the number of words per line.

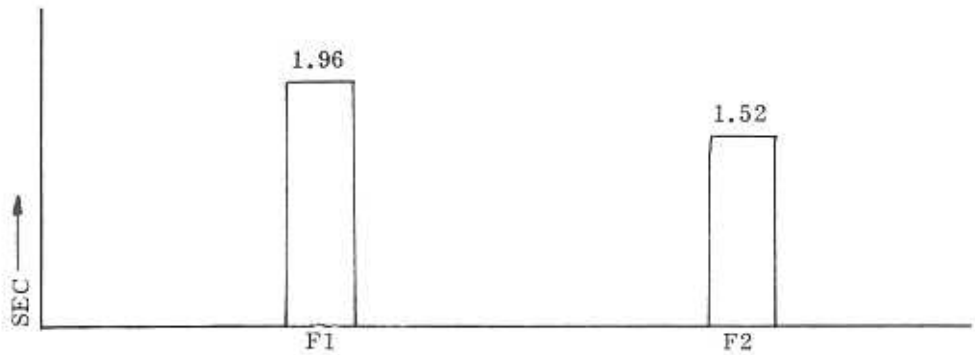
3. T_{reqd} depends upon the type of informational need and effects are similar to these presented and discussed in study F-5.

4. The results obtained from problems B and C indicate that a subject attempts to search information displayed by a sign from top to bottom. Therefore, it can be stated that if the required message is presented in lower lines, the subjects would spend more time acquiring the information as compared to when it is placed in the very first line. Further, the results obtained from the trials involving four line messages (see Figure 4.46) indicates that the subject's dominant search patterns were as follows:

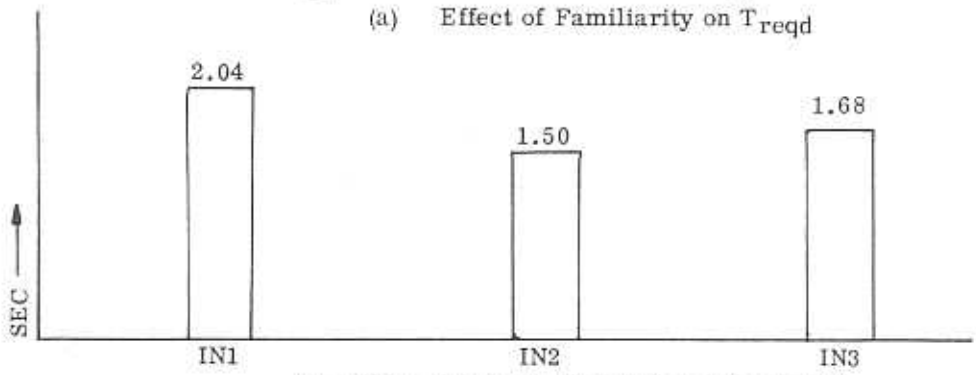
   a. search for needed information in the first line, and

   b. if the information is not found, then search in the lines in the following order: third line, then the second, and, finally, the fourth.

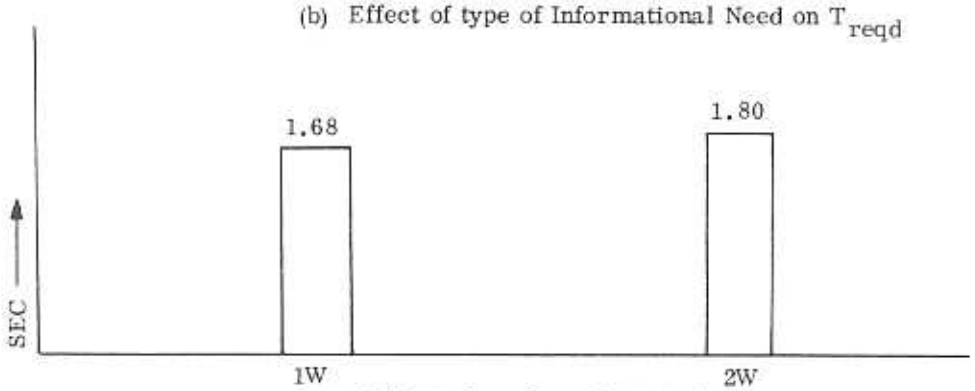
5. As mentioned earlier, this experiment was primarily conducted to determine if the data on T_{reqd} can be obtained under laboratory conditions. Figure 4.47 presents the grand mean and marginal means obtained from this study (problem A) and study F-5. It should be noted that in both the studies the data was obtained by using similar types of messages. The comparisons of the values of T_{reqd} presented in Figure 4.47 show that consistantly the values of T_{reqd} obtained under actual driving situations are higher than those obtained under similar conditions in the laboratory. Further, the results show that the effect of increase in message content and complexity of informational need increases values of T_{reqd} in the actual driving situations more sharply as compared to similar increase under laboratory situations. Figure 4.48 illustrates the above described effect.



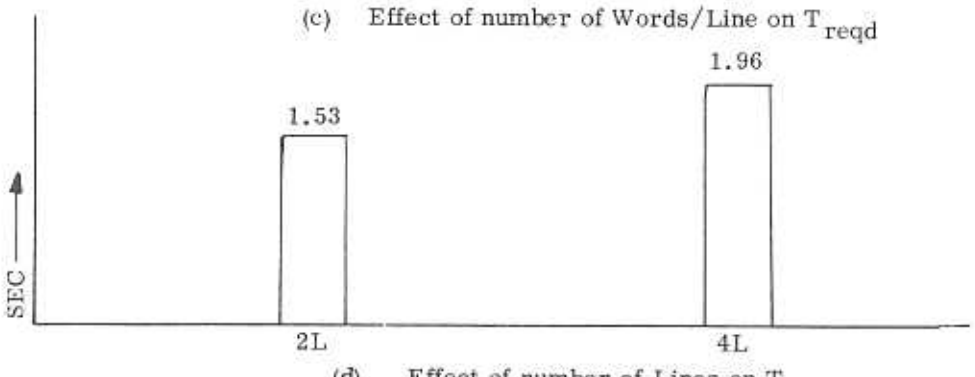
(a) Effect of Familiarity on T_{reqd}



(b) Effect of type of Informational Need on T_{reqd}

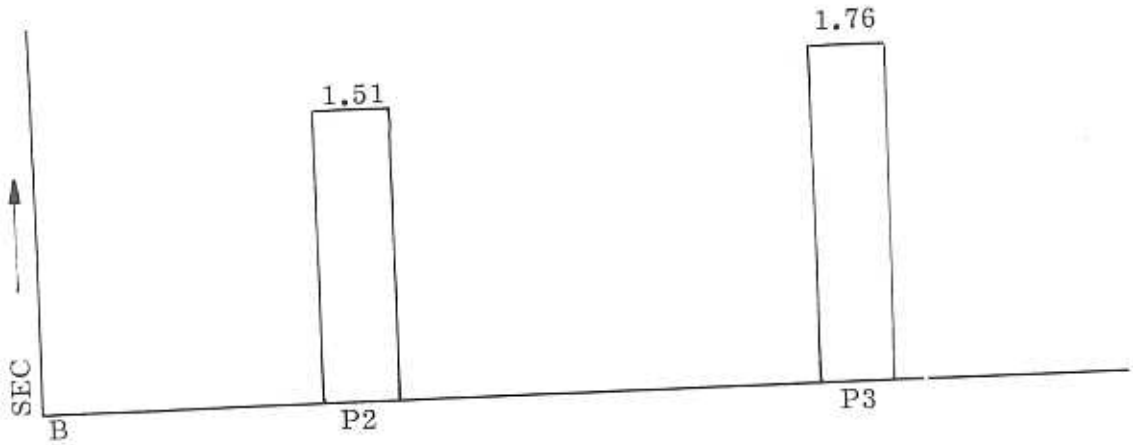


(c) Effect of number of Words/Line on T_{reqd}

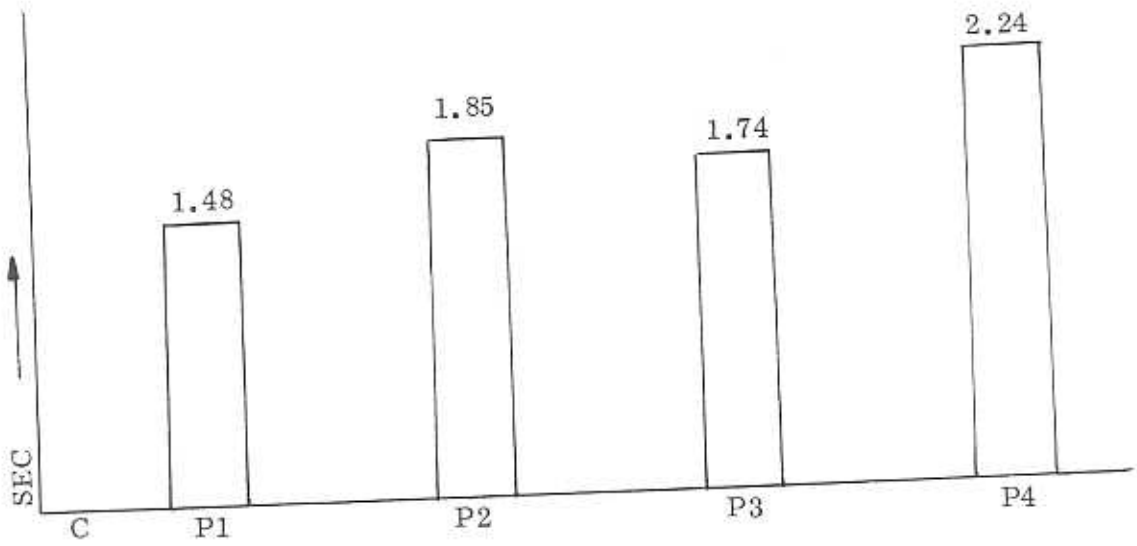


(d) Effect of number of Lines on T_{reqd}

Figure 4.45.--Marginal Means of T_{reqd} Obtained as a Function of Levels of: a) familiarity, b) type of informational need, c) number of words/line, and d) number of lines on the sign



(a) --Effect of line position of needed information on T_{reqd} when the displayed message consisted two lines (from Problem B)



(b) --Effect of line position of needed information on T_{reqd} when the displayed message consisted four lines

Figure 4.46.--Marginal Means of T_{reqd} Obtained as a Function of the Line Position of the Needed Information in the Displayed Message on a Sign

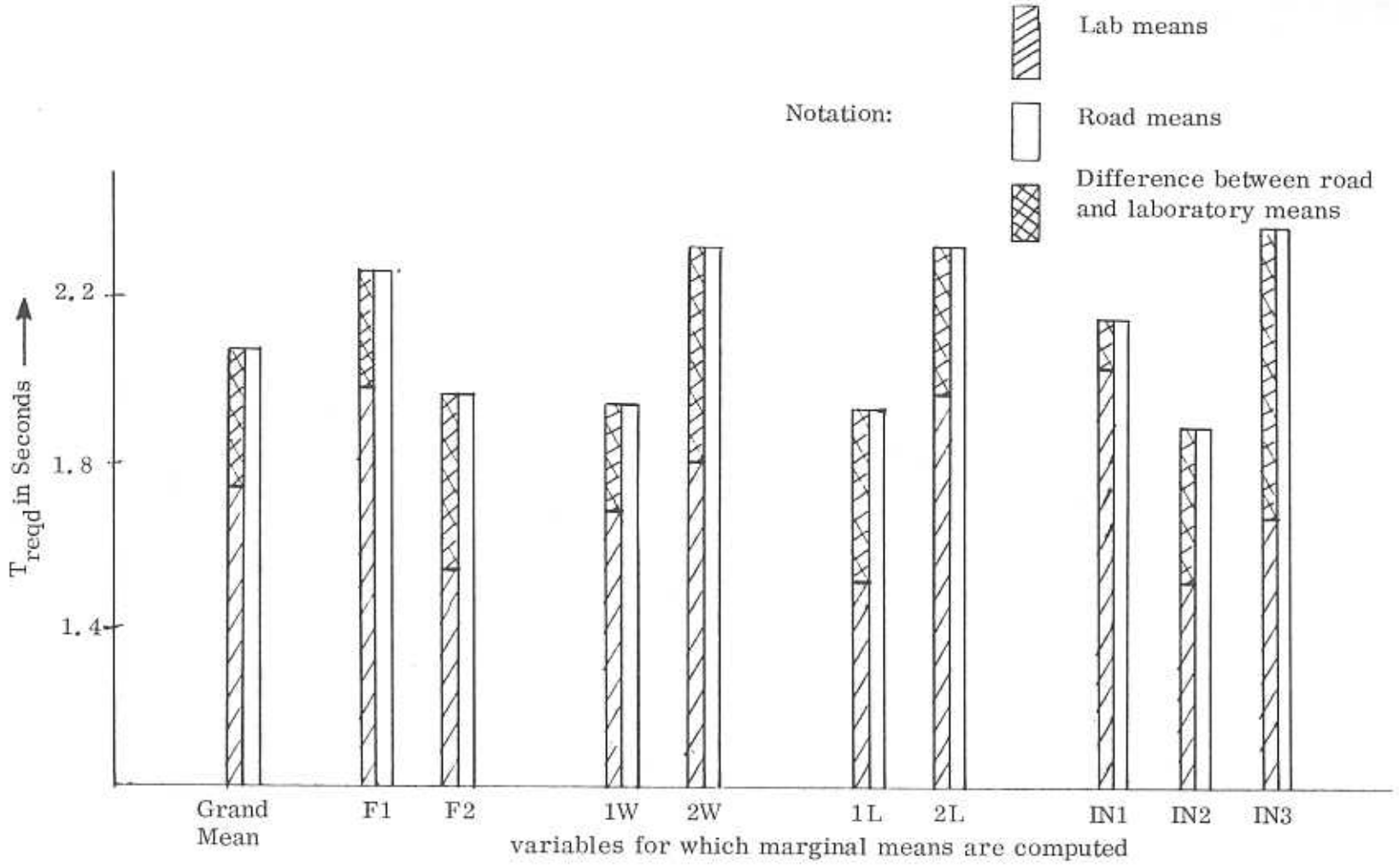


Figure 4.47.--Comparison of Values of T_{reqd} Obtained from Road and Laboratory Data

Of course, these differences in the T_{reqd} values obtained in the field and in the laboratory tasks are expected as the subject needs only to concentrate on the reading task in the laboratory situations. Further, the comparison made here is based on the tested "information signs". If "guide signs" are tested similarly under the field and laboratory experiments, it appears that the sign reading behavior of the drivers would be considerably different under field situations as compared to the laboratory situation.

There is no doubt that additional research work will be required to predict values of T_{reqd} with higher accuracy for actual driving situations on the basis of laboratory studies. But the results do indicate a possibility of predicting values of T_{reqd} on the basis of laboratory work.

Study L-3

Title: Determination of relationship of Reading Time (T_{reqd}) to the Amount of Message Acquired in Sign Reading

Objectives: The primary objective of this study was to gain some insight into the problem of determining the amount of message that a subject can receive in successive fixations.

In the field experiments it was found that in many situations drivers do not read the entire message presented by a sign. The drivers, depending upon the visual load (due to visual informational need for performing driving tasks other than the sign reading task) and type of informational need (in obtaining information fron a sign) generally only read a part of the total message displayed by a sign. The independent variable considered for this experiment was the amount of message displayed on a sign and it was studied at three levels.

DESCRIPTION OF THE EXPERIMENT

In this experiment twenty-four slides of signs were selected from the slides of the signs used in study L-2. The twenty-four slides included eight different signs of the three types as shown in Figure 4.49. The twenty-four signs were randomly ordered for presentation to the subjects. Each sign was presented to each of the two subjects in tachistoscopic exposures of 200 msec. in duration. It should be noted that 200 msec. duration was used for tachistoscopic exposures as the data collected in all the field experiments showed that mean durations of fixations that provided information about the signs were approximately 200 msecs. in duration.

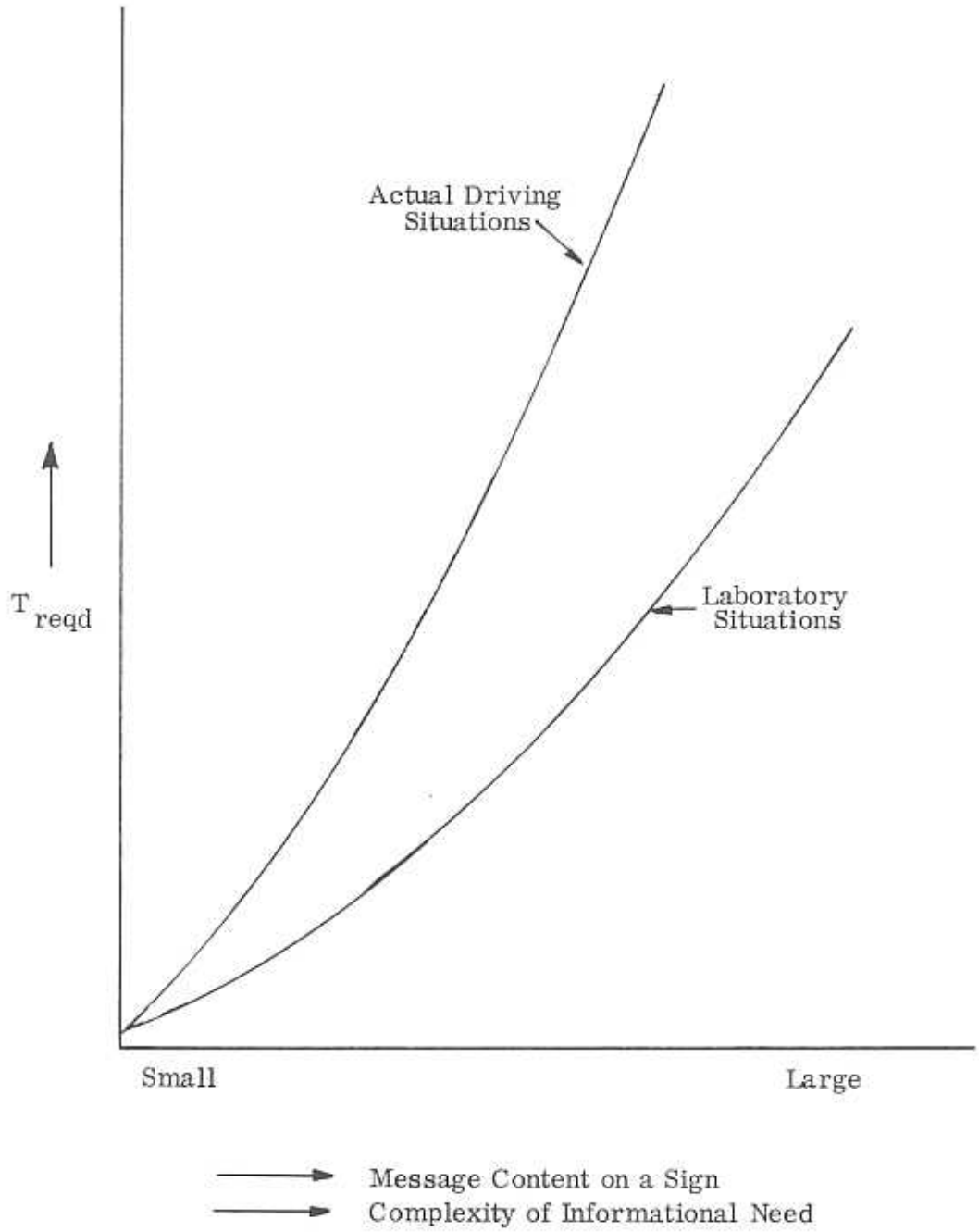


Figure 4.48.--Conceptual Illustration of the Effect of Actual Driving versus Laboratory Conditions on T_{reqd}

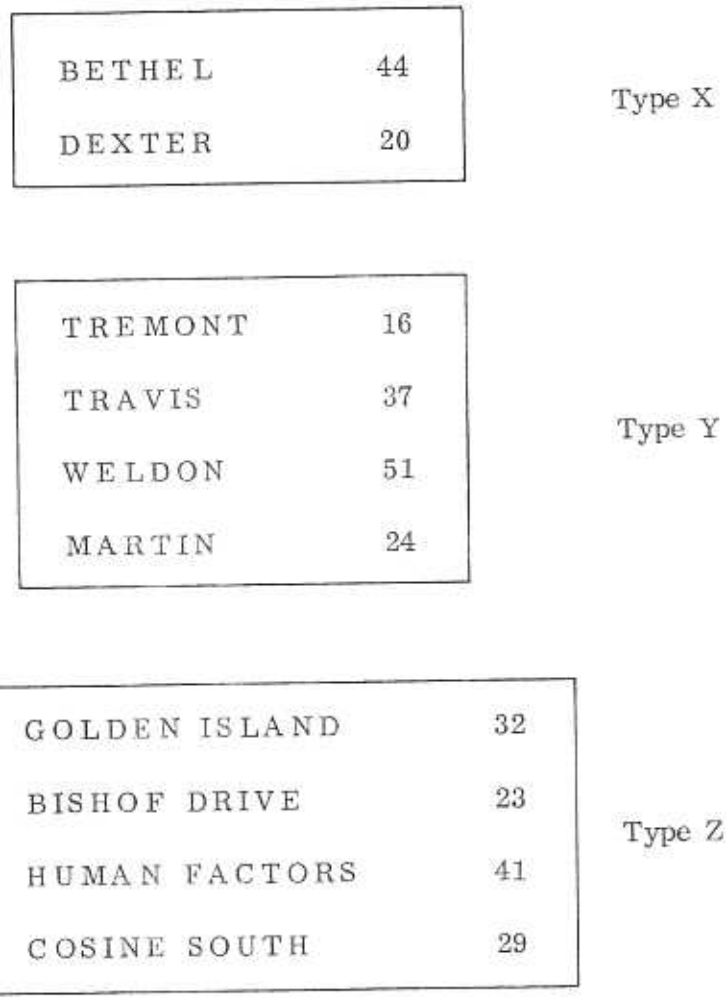


Figure 4.49.--Examples of Signs Presenting Different Amounts of Message Used in the Study L-3

Two subjects with normal vision participated in this experiment. The subjects viewed the signs from a distance of 15 feet and the angle subtended by the letters was about 2 degrees.

The subjects were instructed to read as much of the message in every presentation and were asked to recite the acquired message. If a subject could not obtain the entire message on the presented sign in an exposure then he was given more exposures (up to 10 exposures) to obtain the remaining message. It should be noted that prior to each presentation of the slides the subject was given a signal to get ready and fixate on a screen. The dependent variable, thus, was the amount of message (in words) acquired in every successive exposure of 200 msecs. in duration.

Results

For the determination of the amount of message acquired, the milage numbers on the signs were regarded as words. Figure 4.50 presents the cummulative percentage of message read by the subjects as a function of number of exposures. It should be noted that the data curves presented in Figure 4.50 are for pooled data of both the subjects.

The curves presented in Figure 4.50 show that in order to correctly acquire 90% of the total message presented by signs of types X, Y, and Z, are about 0.6, 1.1, and 1.9 seconds are required, respectively.

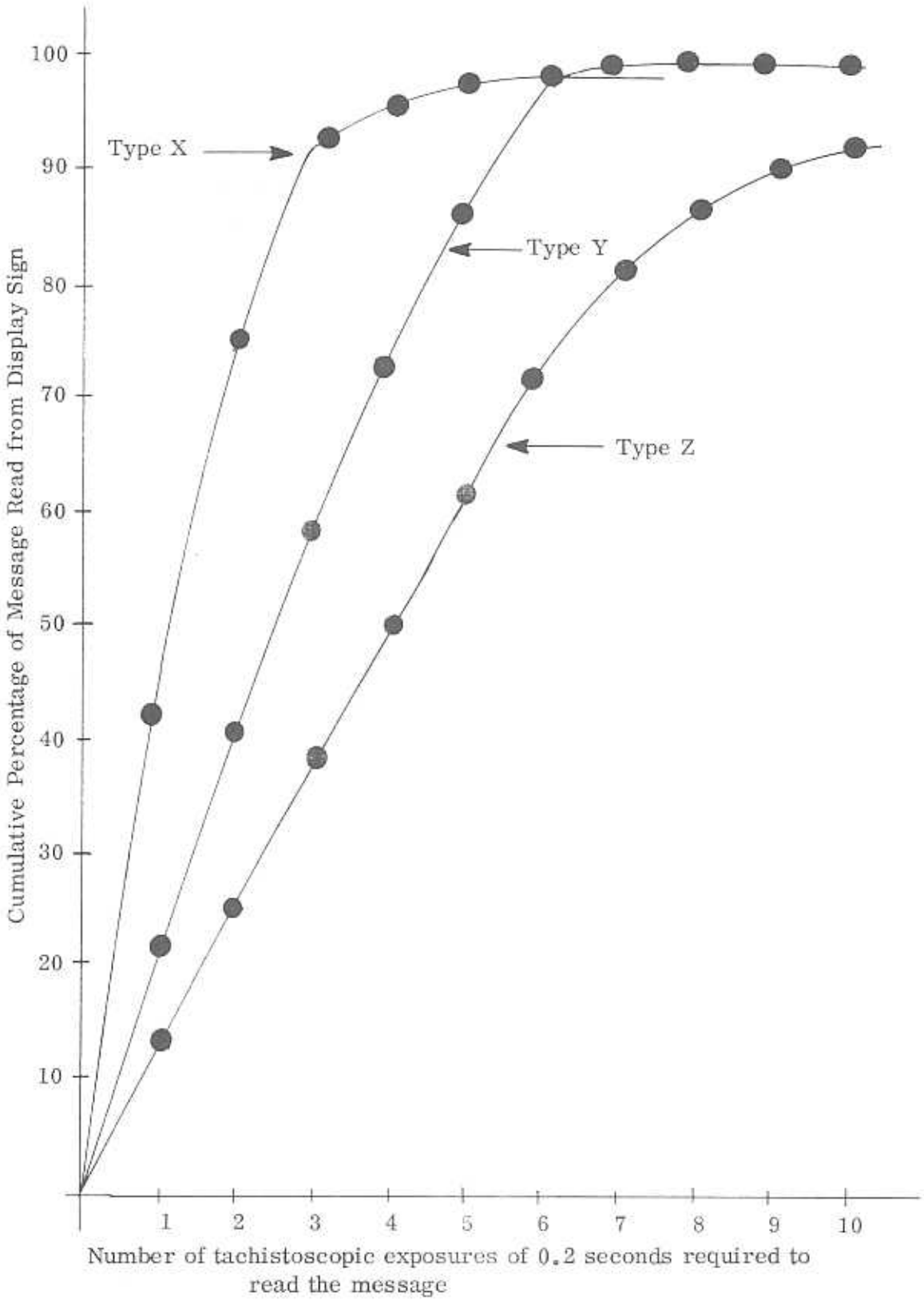


Figure 4.50.--Graph of Time Required to Read Percentage of Total Information Displayed by the Sign