330

HIGHWAY RESEARCH BOARD

Bulletin 330

Driver Characteristics

National Academy of Sciences—
National Research Council

publication 1010

HIGHWAY RESEARCH BOARD

Bulletin 330

Driver Characteristics

Presented at the
41st ANNUAL MEETING
January 8-12, 1962

National Academy of Sciences—
National Research Council
Washington, D.C.
1962

$2.00

Department of Traffic and Operations

Contents

Human Factors Research Reports—AASHO Road Test

I. Field Study of Vigilance Under Highway Driving Conditions

D.A. DOBBINS, J.G. TIEDEMANN, and D.M. SKORDAHL, Human Factors Research Branch, The Adjutant General's Research and Development Command, U.S. Army, Washington, D.C.

• VIGILANCE can be defined as the prolonged ability to detect certain environmental signals. Many individuals who are required to observe infrequent or irregularly spaced visual signals detect a progressively smaller proportion of signals with the passage of time. As found in laboratory studies, the classical decrement in vigilance occurs rapidly during the first thirty minutes of monitoring and then stabilizes at a low detection plateau (14).

In the present study, research opportunity was afforded by the American Association of State Highway Officials (AASHO) Road Test to study signal detection performance under realistic field conditions rather than by the classical laboratory approach. For the Road Test, Army drivers were required to drive trucks on experimental highways under monotonous and fatiguing conditions, thus providing a "natural laboratory" for a study of vigilance. The factors already present in the driving situation which were expected to challenge driver vigilance and consequently allow observation of the extent of performance decline under actual operating conditions included truck noise and vibration, boredom induced by repeated circling of the driving loops, and the sheer physical fatigue caused by driving large and heavily loaded trucks. To these factors were added the energy expenditure demanded by the experimental vigilance task which required each driver to discriminate among nearly 850 signals in order to respond to approximately 210 critical signals over 7 hr of driving.

The specific objectives of the human factors portion of the AASHO investigation were

1. To develop an apparatus test to measure vigilance during the actual driving process.
2. To analyze the vigilance performance of a group of drivers during one full 7-hr driving shift to determine the level of and trends in performance in detecting signals as a function of time spent in monitoring.
3. To determine the extent of individual driver differences in signal detection performance and to estimate the reliability of these differences.

METHOD

Vigilance Tester

A portable apparatus, the U.S. Army Transportation Corps Vigilance Tester, was designed for use on the trucks (for a detailed description of the tester, see 5). The apparatus consisted of a visual signal display unit mounted on the truck dashboard, a foot-operated response pedal, and a combined programer and response recorder unit mounted on the truck bed. The signal display unit was a circular area 5 in. in diameter divided into six red and nine white 24° radial panels with a 150-milliamp light bulb positioned behind each panel. The red panels were arbitrarily designated as the critical areas; that is, requiring a response by the driver whenever a signal appeared in one of the areas. The white panels were designated noncritical signal areas and required no response at the occurrence of a signal. A predetermined program for activating the visual signals (light bulbs) was maintained through the use of a punched tape.

Signals occurred in the display area at a rate of 30 critical and 91 noncritical signals per hour. Intersignal intervals of 5, 10, 15, 20, 30, 50, and 75 sec were used. Both the position of the signals appearing on the display panel and the intersignal intervals that followed were randomized. The duration of both critical and noncritical signals was 1 sec and the driver had 5 sec following each signal in which to respond. Automatic counters were used to record signal and response data.

Subjects

The subjects were 42 enlisted drivers from the AASHO Road Test Support Activity of the U. S. Army Transportation Corps. The only standard used for the selection of drivers was that they had to have been assigned to the particular driving loop for at least one month before testing.

The records of 42 drivers were considered acceptable for the purposes of this report even though many more were tested. The records of many drivers who participated in the experiment were discarded for the purposes of the present study because of interruptions in the driving shifts resulting from malfunctioning of the vigilance tester, truck breakdowns, and need for highway maintenance. The only records used in the statistical analyses were those of drivers who had uninterrupted testing for six consecutive driving periods.

Experimental Procedure

Before beginning a driving shift, drivers were told that lights of 1-sec duration would appear, one at a time, in different red and white panels of the display. Their task was to monitor the display unit while driving the truck and to respond only to light signals appearing in red panels by depressing the foot pedal. Each driver responded to a few practice signals before beginning his driving shift to make sure he fully understood his task.

The monitoring session was a 9-hr driving shift divided into seven periods of 90, 90, 90, 60, 45, 45, and 30 min, respectively—a total of 7½ hr testing time. Five 15-min rest periods and one 40-min meal break separated the driving periods. To prevent confounding day and night effects within a single driving shift, the last 30-min driving period of both the day and the night shift was discarded from the data analysis because it contained the twilight time. The performance measures were taken cumulatively at the end of each period, but no within-period measures could be taken because of recording limitations of the apparatus. Testing for the record began in August 1960 and continued through November 1960.

Performance Measures

The vigilance performance of a driver was evaluated by means of two scores. The first score was "Percent Detections," simply the percentage of critical signals detected, computed as

$$\text{Percent Detections} = \frac{(\text{Number of responses to critical signals})}{(\text{Number of critical signals presented})}(100)$$

The second score was "Percent False Detections"—an index of errors of commission. The total number of false detections made to noncritical and imaginary signals was divided by the number of noncritical signals presented as

$$\text{Percent False Detections} = \frac{\begin{pmatrix}\text{Number of responses}\\\text{to noncritical signals}\end{pmatrix} + \begin{pmatrix}\text{Number of responses}\\\text{to imaginary signals}\end{pmatrix}}{(\text{Number of noncritical signals presented})}(100)$$

Responses to imaginary signals were defined as those instances in which the subject depressed the response pedal even though no signal was on the display unit at the time. Although the inclusion of these errors in the numerator of the performance fraction was questionable mathematically, these two types of false detections seemed to represent the same kind of error and hence were pooled.

Statistical Control Procedures and Analysis

Inspection of the frequency distributions of Percent Detection and Percent False Detection revealed marked skew as well as correlation between means and standard deviations. Thus, to make the data amenable to parametric analysis, each driver's vigilance scores were transformed to arcsins ($X = \arcsin \sqrt{P}$) which satisfactorily reduced these irregularities.

Also, t-tests were performed for possible differences between the mean detection levels for two variables imposed by the nature of AASHO Road Test conditions: (a) driving schedule and (b) the particular experimental loop on which driving was accomplished. Because no significant differences were found for either schedule or loop effects, scores for drivers on different schedules and on different loops were merged.

F-ratios revealed a significant difference between mean detection levels of day shifts vs night shifts. The difference in percent detections between day and night drivers is believed to have occurred because of a difference in the amount of contrast between the signal display and the surround during day and night conditions, and is not considered to reflect true day-night differences in alertness. (The surround of the display unit was the driver's view through the windshield of the truck. The surround during the day driving consisted of colors, movements, and glare not present to nearly the same degree during night driving.) Nevertheless, as a result of this analysis, day and night shift results were kept separate in all subsequent analysis to aid in interpretation.

Analyses of variance were performed on the transformed data to test for differences in vigilance between day and night drivers, vigilance score differences among the means of the six driving periods, and interactions (6, pp. 220-232). The analyses of variance were supplemented by tests for significant trends in the driving period means, and for differences between the slopes of the day-period means and the night-period means (6, pp. 247-250).

Changes in intersubject variability from the first to the sixth driving periods were tested by means of t-tests (18, p. 244). The reliability of individual score differences was estimated by internal consistency analysis.

RESULTS

When the six driving periods for all 42 drivers were combined, it was found that approximately 83 percent of all critical signals were detected—unusually high considering the conditions under which the monitoring task was accomplished. The over-all percent of false detection was also considered low, averaging only 4 percent for all drivers. (As previously reported, the night drivers detected a significantly higher percentage of critical signals than did day drivers; however, no significant difference in percentage of false detections was found between the two groups.) Tables 1 and 2 give the mean percent detections and false detections in arcsin form by driving period for day drivers, night drivers, and for the two groups combined.

Detection levels over the six driving periods for all 42 drivers showed a significant increasing trend, which was linear, instead of the hypothesized decrement. In terms of percent false detection, the total group of 42 drivers demonstrated a significant decreasing trend, also linear, over the six-period driving shift. (Only the night drivers contributed to these significant trends, whereas the day drivers showed no significant increase or decrease for either vigilance measure. Once again, the visibility artifact was suspected to have caused the increasing average level of correct detections. Toward the early morning hours, the surround of the display unit became more homogeneous, making detections of critical signals easier for drivers tested at night.) Figures 1 and 2 show mean percent detection score trends and mean percent false detection score trends, respectively, by driving periods. Table 3 is a summary of F-ratios from trend analyses of period means. No trend of a higher order than linear was found to be significant.

Although average percent detection levels were consistently high, wide individual differences in vigilance performance were apparent. These individual differences in

TABLE 1
PERCENTAGE OF CRITICAL SIGNALS DETECTED BY ROAD TEST DRIVERS IN SIX DRIVING PERIODS (Arcsin Scores)

Period	Day Driving (N = 19)			Night Driving (N = 23)			Total (N = 42)		
	Mean	Std. Dev.	Range	Mean	Std Dev.	Range	Mean	Std. Dev.	Range
1	61.2	9 7	39.2-75.9	72 2	11.0	49.4-90.0	67.2	11.7	39.2-90.0
2	60.3	12.3	40.5-90.0	73 9	10.2	54.3-90.0	67.7	13.1	40.5-90.0
3	60.1	11.5	36.1-80.2	75.0	13.3	36.2-90.0	68.3	14.5	36.1-90.0
4	61.7	10.5	45.6-77.3	73.1	10.9	51.5-90 0	67.9	12.1	45.6-90.0
5	61.8	13.4	43 7-90.0	77.6	11.4	52 9-90.0	70.4	14.6	43.7-90.0
6	59.8	17.6	27.1-90.0	78.3	12.3	53.7-90.0	69.9	17 5	27.1-90.0
All	60.8	10.4	27.1-90.0	75.0	9.4	36.2-90.0	68.6	12.2	27.1-90.0

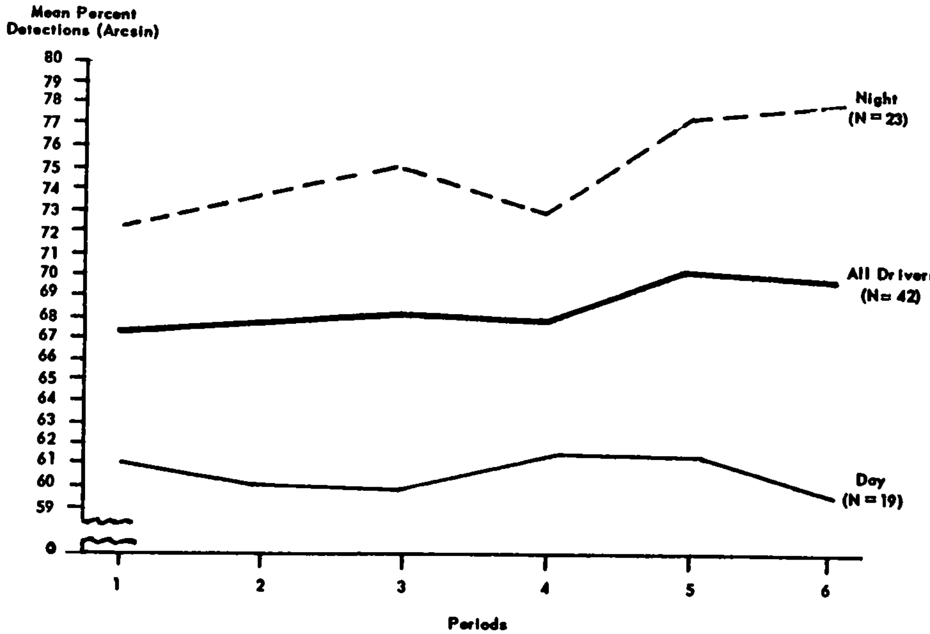

Figure 1. Mean percent detection scores by driving period.

percentage of detections tended to increase as the driving time increased. Tables 1 and 2 give the standard deviations and ranges of transformed scores for each driving period. Intersubject variability in percent detections increased significantly between driving periods 1 and 6. Intersubject variability in percent false detections decreased significantly during the same interval for the total group of 42 drivers. (A significant increase in percent detection variability was obtained for day drivers only, and a significant decrease in percent false detection variability was obtained for night drivers only. A statistical artifact is presumed to have prevented a significant increase in night drivers' percent detection variability. As night drivers' average scores increased during the early morning hours due to better visibility, individual score variation was limited by the 100 percent upper score limit. Day drivers whose visibility remained fairly constant did not show the steady increase in average percent detection scores, and their

TABLE 2

SCORES ON FALSE RESPONSE MEASURE FOR ROAD TEST DRIVERS IN SIX DRIVING PERIODS (Arcsin Scores)

Period	Day Driving (N = 19)			Night Driving (N = 23)			Total (N = 14)		
	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range
1	8.4	5.8	0-20.4	10.4	9.3	0-42.4	9.5	7.9	0-42.4
2	10.8	9.3	0-36.7	9.6	11.6	0-40.6	10.1	10.7	0-40.6
3	7.3	5.6	0-19.2	8.9	8.0	0-31.2	8.2	7.1	0-31.2
4	9.8	14.5	0-66.3	7.0	6.2	0-15.9	8.2	10.8	0-66.3
5	9.1	11.7	0-43.9	6.0	6.5	0-18.3	7.4	9.3	0-43.9
6	4.9	5.0	0-14.5	6.5	5.9	0-17.0	5.8	5.6	0-17.0
All	8.4	5.7	0-66.3	8.1	6.0	0-42.4	8.2	5.9	0-66.3

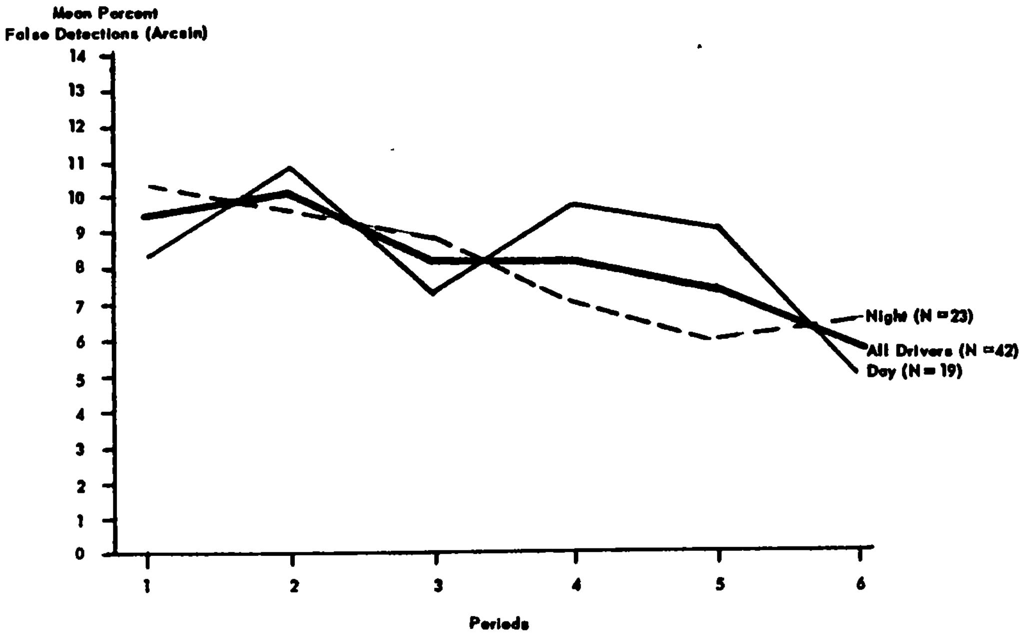

Figure 2. Mean false detection scores by driving period.

performance was consequently more free to vary toward the end of their driving shifts. The significant decrease in variability of false detections may be similarly accounted for.) Table 4 shows the significance of changes in variance between driving periods 1 and 6 for both vigilance measures.

The reliability of individual differences for both vigilance measures was high. Reliability coefficients, computed between scores on odd-numbered and even-numbered driving periods, and augmented by the Spearman-Brown formula, were 0.93 and 0.88 for percent detections and percent false detections, respectively. Table 5 gives the reliability coefficients for both vigilance measures using odd vs even periods and first vs sixth driving periods. The latter analysis showed moderately high stability of percent detection scores (r =0.67) and lower stability of false detection scores (r = 0.25) even between scores separated by 5½ driving hours.

In summary the four major findings of this investigation were (a) the high percentage detection and low percentage false detection levels; (b) the lack of decrement in vigilance as a function of time spent monitoring; (c) the high reliability of individual differences; and (d) increased variability in percentage detection performance as a function of time spent monitoring.

TABLE 3

SUMMARY OF F-RATIOS FROM TREND ANALYSES OF PERIOD MEANS OF VIGILANCE MEASURES
(Arcsin Scores)

Detection	Periods	Trend (%)		
		Linear	Quadratic	Residual
Signal	Day only	0 0	0 0	0 4
	Night only	8.4[a]	0 3	0 8
	Total	4 4[b]	0 1	0.5
	Day/night × period	4 8[b]	0 3	0.4
False	Day only	2 0	2 0	1 1
	Night only	6 1[b]	0 1	0.2
	Total	7 7[a]	0 5	0.3
	Day/night × period	0.8	1 5	0 9
df		1/200	1/200	3/200

[a]Trend significant beyond 1 percent point.
[b]Trend significant beyond 5 percent points.

TABLE 4

SIGNIFICANCE TESTS OF DIFFERENCES IN VIGILANCE TEST SCORE VARIANCE BETWEEN DRIVING PERIODS 1 AND 6
(Arcsin Scores)

Detection	Periods	Variance Period 1 (%)	Variance Period 6 (%)	$S^2_6 - S^2_1$ Diff	p[a]
Signal	Day	94 09	309 76	+215 67	0 01
	Night	121 00	151 29	+ 30 29	N S
	Over-all	139 24	306 25	+167 01	0 01
False	Day	33 64	25 00	- 8 64	N S
	Night	86 49	34 81	- 51 68	0 05
	Over-all	62 41	31 36	- 31 05	0 05

df day = 18, night = 22, over-all = 41

[a]Based on two-tailed t-tests

INTRODUCTION

Prolonged High Detection Levels

Not only did the expected decline in performance as a function of time spent in monitoring fail to occur but a significant linear increase in percent detections was found during the 7 hr of driving. Also, contrary to expectations, a significant linear decrease in percent false detections was found over driving shifts. (A procedural difficulty of the present experiment was the inability to record responses at intervals within driving periods. There is a possibility that some performance decrement occurred within driving periods but did not appear in the response measures because they were recorded at the end of driving periods. However, it is certain that within-period decrement did not occur to a great extent because the over-all high detection levels left little freedom for within-period variance.)

At least two previous experiments have shown that noise and vibration such as were present in the driving situation have a demonstrable effect of monitoring behavior (11, 13). The fact that 100 percent critical signal detection accuracy was not obtained in the present study indicates these factors may have had some influence on the vigilance performance of the drivers. The high detection levels indicate, however, the presence of compensatory factors that tended to overcome these decrement-inducing conditions. New information, in the form of recent research by other investigators, allows more enlightened speculation as to the nature of these compensatory factors.

Signal Characteristics.—Four major signal characteristics seem to be the most probable contributors to the prolonged high detection levels. These are the high rate of presentation of noncritical signals, the highly stimulating signal environment caused by the divided-attention nature of the task, the relatively restricted range of intersignal intervals, and the relatively long signal duration.

The "filter theory" of Broadbent (3) suggests that irrelevant signals during a monitoring task would tend to make the task more difficult because the monitor would be more likely to respond to false signals, and consequently miss more critical signals, with the passage of time. Many noncritical signals were programed into the present experiment. In apparent contradiction to Broadbent's theory, however, two recent studies (7, 16) have shown that the introduction of irrelevant signals into the monitoring task actually enhanced monitoring performance under certain conditions. The effect is marked when the artificial signals are perceptually similar to the real signals. In the present study, critical and noncritical signals were identical in all aspects except for the fact that critical signals appeared in red panels and noncritical signals in white panels. It seems probable that the high rate of perceptually similar noncritical signals used in the present study actually enhanced alertness.

TABLE 5

RELIABILITY COEFFICIENTS FOR VIGILANCE PERFORMANCE MEASURES
(Arcsin Scores)

Driving Period	Measure	Day Driving	Night Driving	Total
Odd vs even	Percent signal detection	0.94[a]	0.88[a]	0.93[a]
	Percent false detections	0.87[a]	0.91[a]	0.88[a]
First vs sixth	Percent signal detection	0.52	0.64	0.67
	Percent false detections	0.50	0.09	0.23

[a] Augmented by Spearman-Brown formula.

Another possible explanatory factor was the high complexity of the stimulus surround caused by the "divided-attention" aspect of the study. Studies of "complex" vigilance (that is, the monitoring of multiple signal sources) have reported no decline in vigilance (10, 11); however, the over-all detection levels reported were much lower than those of the present study. Moreover, the amount of environmental stimulation received from sources other than experimental signals was high and may have enhanced alertness. Hebb's "arousal" theory (8) proposes that high detection levels are a function of an optimal level of cortical arousal. The maintenance of cortical arousal is a function of the total stimulus input, according to Hebb, regardless of whether that stimulation is relevant to the monitoring task at hand. The present results seem to support Hebb's views.

Two other factors of the present experiment that may have helped prevent the appearance of a performance decrement were the relatively long 1-sec signal duration, and the relatively restricted range of intersignal intervals.

Task Characteristics.—Task factors that may have contributed to the lack of performance declines were the high degree of perceptual-motor activity level, progressively diminishing lengths of driving periods during a shift, and the presence of interpolated rest pauses.

Drivers, in performing their normal driving duties simultaneously with the experimental vigilance task, were engaged in a great deal more perceptual-motor activity than that required of laboratory subjects passively monitoring experimental displays. Ray, Martin, and Alluisi (20) have pointed to the conflicting results between active and passive vigilance tasks and have suggested that the degree of active participation required by the subject may make a critical difference in the appearance of performance decrement.

Two other aspects of the road test engineering research design probably helped maintain high detection levels. These were the diminishing length of driving periods as shifts progressed, and the interpolated rest pauses between driving periods. These two factors, planned by road test personnel for the lessening of driver fatigue, probably helped in maintaining alertness.

Subject Characteristics.—In the present study it is suspected that driver motivation may also have played a role in the maintenance of high detection levels. Most drivers seemed interested in the task and many who were not tested requested it. It is also suspected that the sources of motivation were extrinsic to the experimental task itself and could be attributed to relief from driving boredom. Many drivers, because they were also soldiers, had lingering suspicions that their performance might somehow be entered into their official service records, in spite of instructions to the contrary. This suspicion may have been an incentive to do well on the experimental task.

The role of motivation in vigilance has not been systematically studied. However, Adams and Chiles (1) found that highly motivated subjects were able to perform complex monitoring and cognitive tasks under fatiguing work schedules for as long as 15 days without serious performance decrement. Adams and Chiles used a realistic space mock-up apparatus in their experiment. Their task appeared to have much more face validity for their subjects than many others typically used in laboratory studies. This realism may help explain the high performance levels found in their study.

Extent and Stability of Individual Performance Differences

The finding of wide initial individual differences in vigilance levels and the relatively high stability of these individual differences during a complete driving shift suggests classifying the vigilance phenomenon among other relatively enduring aspects of the individual. High score reliability, if found for acceptable retest intervals, will qualify the vigilance phenomenon as a profitable subject area for psychologists interested in the prediction of individual differences. Only recently have some attempts been made to conceptualize the vigilance phenomenon as an attribute of the individual observer. These attempts are discussed in Part II of this paper.

The increased variability in percentage detections during a monitoring period is a common finding in vigilance research. Buckner, Harabedian, and McGrath (4) present evidence that detection variability increases not only in percentage measures but also in measures of threshold sensitivity and response latency. The explanation suggested by these data is that initial individual differences in vigilance levels became more exaggerated due to increasing motivational differences among subjects as boredom and monotony come more into play toward the end of the monitoring period.

CONCLUSIONS

In spite of inhibitory factors present in this study which would lead to a prediction of performance decrement (noise, truck vibration, long hours, boredom, and fatigue), other compensatory factors also present may have combined to cause prolonged high detection levels. The influence of inhibitory factors was apparent in increases in variability of performance, rather than in levels of performance.

Possible compensatory factors discussed were (a) signal characteristics, including high rate of noncritical signals, complexity of over-all stimulus conditions resulting from the divided-attention task, low range of inter-signal intervals, and high signal duration, (b) task characteristics, including high perceptual-motor activity level, interpolated rest pauses, and diminishing length of driving periods; and (c) subject characteristics, including motivation. The lack of within-period performance measures of the present study precluded precise comparisons with laboratory experiments. The present study, however, showed that detection performance began at a high level and stayed at a high level in spite of noxious monitoring conditions. Along with other research on active and complex monitoring tasks, the present study suggests the rapid, severe decrement found in the passive monitoring of laboratory displays may be of limited generality. The results of the latter type of study do not seem to represent human monitoring proficiency adequately when the monitoring task is meaningful and when monitors are fairly active physically. The classical decrement curve may represent a basic and significant perceptual phenomenon under conditions of reduced organismic stimulation. However, it is felt that investigators who advise military and industrial management on such factors as personnel monitoring schedules should attempt more realistic simulation of representative signal environments and conditions of work. Otherwise, there is a danger of seriously underestimating human monitoring capacity on a great many operational tasks.

II. Prediction of Vigilance

D.A. DOBBINS, D.M. SKORDAHL, and A.A. ANDERSON, Human Factors Research Branch, The Adjutant General's Research and Development Command, U.S. Army, Washington, D.C.

• PART I of the present report described a study of trends in vigilance performance of a group of drivers during a seven hour driving shift. The present report deals with the prediction of individual differences in vigilance.

The aspect of vigilance that has been of most concern to researchers is the demonstrated reduction of signal detection proficiency by human monitors as a function of monitoring time. Many experimental studies have investigated the various parameters of vigilance tasks that influence detection performance for groups. In the course of these researches, wide individual differences in detection proficiency present even at the beginning of the monitoring period have been noted. In spite of the fact that individual differences in vigilance were recognized and attempts were made for their measurement as early as the 18th century (19), relatively little direct study has been accomplished until recently.

Although there is a great deal of evidence that individual differences in vigilance performance are reliably measured within a typical monitoring period (2, 4, 5, 9), there is little evidence that retest reliability over long intervals is sufficiently adequate to justify prediction attempts. There is even less evidence that standardized psychological measures are useful predictors of vigilance (2, 12, 15, 17). These studies have shown that correlation coefficients between psychological predictors and vigilance criteria are usually nonsignificant; but if significant, then low and sometimes disappearing on cross-validation; and that personal variables interact with task variables and thus frustrate attempts at generalized prediction.

OBJECTIVES AND METHOD

The present study was an attempt to predict vigilance performance using a greater variety of psychological predictor measures than is usually reported in vigilance research. The specific objectives were the following:

1. To examine the reliability and interrelationships between two measures of vigilance performance.
2. To determine the predictability of the vigilance criteria using a wide variety of standardized psychological tests and other measures.

Primary interest was in determining which, if any, of several well-known psychological domains hold most promise for the prediction of vigilance. The approach was empirical and no provision was made for cross-validating results. For these reasons the study is considered merely exploratory.

Samples

Subjects were 111 enlisted truck drivers furnished by the U.S. Army Transportation Corps to drive loaded vehicles around experimental highway surfaces of the Road Test project. The average age of the group was 22.7 years, the average years of formal education was 10.5 years, and 42 percent were enlistees.

Only two standards were set for the inclusion of drivers in the experimental group: (a) drivers must have been assigned to a particular driving loop for at least one month prior to vigilance testing (this standard was set to minimize the danger of divided attention between the driving task and the experimental vigilance task); and (b) during vigilance testing, each driver must have been exposed to at least 150 visual signals (5). This number of signals represents 1¼ hr of uninterrupted testing time, considered necessary to achieve minimum acceptable score stability. Not all drivers could be tested for this length of time because of apparatus unreliability. Scores derived from less than 150 signal presentations were excluded from analysis.

The group of 111 drivers was separated into two samples, day drivers (n = 51) and night drivers (n = 60), based on the previous finding that significant differences in over-all detection levels, trends, and inter-subject variability were found between day-shift and night-shift drivers. These samples were kept separate in the present study because different factors seemed operant in day and night vigilance scores. These factors might have differentially influenced prediction.

Data Collection

Predictor tests were administered to drivers before their driving at the Road Test. (Four of the 111 drivers were administered predictor tests after they had begun driving; however, their predictor testing preceded their criterion testing.) Tests were administered to drivers either at Ft. Eustis, Va., or at the AASHO Road Test site. Other predictor variables were gathered from the official service records. All predictor variables, including sources, are described by Dobbins, Tiedemann, and Skordahl (5). Predictor testing was administered to each newly assigned group of drivers continuously from August 1959 to August 1960.

Vigilance Testing was begun in August 1960 and continued through November 1960. Drivers were assembled in crew shacks before testing and were read standard instructions to the effect that they were participants in a human factors research experiment; drivers were urged to do their best on the vigilance task within the limits of driving safety. After a brief familiarization period with the Transportation Corps Vigilance Tester, drivers began their normal driving shift which consisted of circling one of five experimental driving loops in heavily loaded commercial trucks. Drivers saw light signals appear one at a time from the dashboard-mounted circular signal display units. Six of the panels covering the light sources were painted red and the remaining nine, white. The driver's task was to depress a foot-pedal when a light appeared in a red panel. Signals appearing in red panels were designated "critical" and appeared at the rate of 30 per hr; signals appearing in white panels were designated "noncritical," and appeared at the rate of 91 per hr.

Variables

Criteria.—Two vigilance criterion scores were developed for each driver. The first score was simply the percentage of critical signals detected:

$$\text{Percent Detections} = \frac{\text{Number of responses to critical signals}}{\text{Number of critical signals presented}}(100)$$

The second vigilance score was an index of errors of commission. This score included the number of responses to noncritical signals added to the number of responses to imaginary signals divided by the total number of noncritical signals presented:

$$\text{Percent False Detections} = \frac{\begin{array}{c}\text{Number of responses}\\ \text{to noncritical signals}\end{array} + \begin{array}{c}\text{Number of responses}\\ \text{to imaginary signals}\end{array}}{\text{Number of noncritical signals presented}}(100)$$

Most drivers were tested for two driving shifts in order to obtain an estimate of criterion reliability. For both of the preceding measures, the total vigilance score used in validity analyses was the sum of the two shift scores.

Two nonvigilance criteria were also developed. These were selected to reflect both general performance as a driver and general morale level. The primary purpose of including these variables was to examine their intercorrelations with the vigilance criteria. Investigators felt that their inclusion might help bring psychological meaningfulness to the interpretation of vigilance. There was no intrinsic interest in the predictability of either of the following two criteria by the predictor variables:

Over-all Adaptability Rating. This was a general performance measure completed by noncommissioned officer crew chiefs. The total score was a summation of points alloted to the following seven rating factors: military bearing, driver proficiency, driver dependability, extent of supervision required, promotability, interpersonal relations, and effectiveness as a team member.

TABLE 6

RELIABILITY COEFFICIENTS OF VIGILANCE CRITERIA

Criteria	Between Two Partial Shifts (avg. of 7.8 hr driving)				Within One Full Shift (7 hr driving)			
	Day$_1$ vs day$_2$ (n = 67)		Night$_1$ vs night$_2$ (n = 81)		Within day (n = 19)		Within night (n = 23)	
Percent detections	0.44	0.61[a]	0.41	0.58[a]	0.88	0.94[a]	0.78	0.88[a]
Percent false detections	0.26	0.42[a]	0.38	0.55[a]	0.77	0.87[a]	0.83	0.91[a]

[a]Augmented by Spearman-Brown formula.

Morale Inventory. This instrument is a standard U.S. Army morale measure completed by the drivers to assess attitudes toward several aspects of army life.

Predictors. — A total of 39 predictors and two reference variables were assembled. The various tests and other measures were arbitrarily grouped into eight predictor clusters. Tests were included within a cluster when they appeared to have been drawn from the same general psychological domain. The clusters are briefly described in the following section; descriptions of specific tests within each cluster have been furnished by Dobbins, Tiedemann, and Skordahl (5).

1. Physical:—Included four predictors—height, weight, visual acuity, and field of vision.
2. Psychomotor:—Included four predictors of eye-hand coordination and foot reaction time.
3. Perceptual Speed:—Included five predictor tests of the speed and accuracy of visual recognition and matching.
4. Cognitive:—Included six predictor tests of verbal, number, reasoning, spatial, and mechanical abilities.
5. Driver Aptitude:—Included five predictor scores from standardized army driver batteries, practical driver tests, and driving knowledge.
6. Personal History:—Included six measures—age, component—(enlistees vs draftees), years of education, marital status, history of grade reductions, and pre-assignment sick call rate.
7. Personality:—Included three self-report personality inventories calling for responses to a wide variety of questions about the self, others, society, authority, and other topics.
8. Attitudinal:—Included two measures of attitudes toward the specific subject of driving. One was a standardized driver attitude instrument; the other was a rating measure of essays written by drivers expressing their attitudes toward assignment at the AASHO Road Test site.
9. Reference:—Two variables were included for potential usefulness in explaining the interrelationships among preceding predictors and the vigilance criteria. These were total amount of time spent by drivers at the road test site, and the total number of miles driven.

Statistical Analyses

Because of skewed distributions, vigilance criteria were converted to normalized standard scores. Within the day and night samples, scores derived from separate testing sessions on different driving shifts were correlated to estimate between-shift reliability. Correlation coefficients, both Pearson product-moment and point-biserial as applicable, were computed between predictor and criterion variables. Validity coefficients were corrected for criteria attenuation.

TABLE 7

INTERCORRELATIONS, MEANS AND STANDARD DEVIATIONS OF CRITERIA

Sample	Criterion Variables	Mean	SD	Intercorrelations		
Night	(1) Percent detections	50.02[a]	10.18	(1)		
	(2) Percent false detections	52.60[a]	8.24	-0.25	(2)	
	(3) Over-all adaptability rating	23.92	3.76	-0.16	0.19	(3)
	(4) Morale inventory	101.68	21.04	0.20	-0.16	0.28[b]
Day	(1) Percent detections	49.08[a]	9.53	(1)		
	(2) Percent false detections	51.69[a]	7.36	-0.02	(2)[c]	
	(3) Over-all adaptability rating	24.70	2.71	0.03	-0.36	(3)
	(4) Morale inventory	98.76	25.64	-0.04	0.11	0.28[b]

[a]Normalized: mean of 50 and standard deviation of 10.
[b]Significant beyond the 0.05 level.
[c]Significant beyond the 0.01 level.

RESULTS

Table 6 summarizes the reliability analyses. In general, the augmented coefficients were low; three were below the 0.60 level set as the minimum acceptable reliability coefficients by some investigators.

The between shift coefficients were considerably lower than the within-shift coefficients reported in Part I for a smaller group of drivers. Other than the general fact that retest coefficients are usually smaller than internal consistency coefficients when computed for the same measure, two other factors may have contributed to the low reliability of between-shift coefficients. These factors were variable lengths of testing time from one driver to another, and variable lengths of time elapsing between the first and second testing sessions.

In general, there was little communality among the various measures. Percent Detections and Percent False Detections correlated only -0.25 in the night sample and -0.02 in the day sample; neither coefficient reached the 5 percent level of significance.

The only criterion variable that shared a significant degree of variance with other criteria was the Over-all Adaptability Rating, a measure of general driver performance. This rating correlated 0.28 with the Morale Inventory in both the day and night samples, and -0.36 with Percent False Detections in the day sample. Table 7 summarizes intercorrelations among the four criteria.

Only twelve validity coefficients were significant at or beyond the 5 percent level for either of two criteria in two independent samples. This relative frequency of significant coefficients was roughly at chance expectations. However, the large number of predictors with positive relationships with "good" criterion performance (percent detections) and negative relationships with "poor" criterion performance (percent false detections) suggested a low amount of valid variance in many predictors. Validity coefficients were consequently corrected for criterion attenuation. The correction was based on an assumed 0.85 reliability coefficient. This level of reliability was considered the maximum attainable under realistic testing conditions. The average level of validity was still low, however, even after the correction.

In terms of the relative number and pattern of significant coefficients, the Personality, Personal History, Driver Aptitude, and Perceptual Speed clusters, respectively, were the most promising for future research. The Cognitive, Physical, Psychomotor, and Attitudinal clusters were less promising. Table 8 summarizes the validity analyses.

The major results of this study were as follows:

1. Between-shift reliability estimates of vigilance criteria were low, ranging from 0.42 to 0.61.

TABLE 8

VALIDITY COEFFICIENTS FOR VIGILANCE CRITERIA

Predictor Variable	Percent Detections				Percent False Detections			
	Day (N = 51)		Night (N = 60)		Day (N = 51)		Night (N = 60)	
	Uncorrected	Corrected[a]	Uncorrected	Corrected[a]	Uncorrected	Corrected[a]	Uncorrected	Corrected[a]
Physical								
Height	-07	-08	00	-01	01	01	09	12
Weight	05	05	21	25[b]	-02	-03	02	02
Visual acuity	05	05	-03	-04	-30[b]	-43[c]	12	15
Field of vision	-01	-01	19	23	-03	04	04	16
Psychomotor								
Foot reaction time	-10	-12	02	03	10	15	-23	-28[b]
Two-hand coord	15	18	-04	-05	-05	-07	-16	-19
Aiming	-05	-06	03	03	-08	-12	-15	-19
Tapping	01	01	-04	-05	00	01	-09	-11
Perceptual speed								
Attention detail	16	19	07	09	-30[b]	-43[c]	-11	-14
Army cler speed	11	13	06	08	02	02	-29[b]	-36[c]
Percept speed	07	09	14	17	-06	-08	-02	-03
Reaction to signals	08	10	15	19	-08	-11	-09	-11
Identical pictures	18	21	08	09	-11	-15	-12	-15
Cognitive								
Verbal	04	05	18	22	-02	-02	-22	-28[b]
Arith reasoning	10	11	02	03	-14	-20	-22	-28[b]
Pattern analysis	11	13	-11	-13	-13	-18	-07	-08
Mech. aptitude	17	20	-04	-04	12	17	-12	-15
Following directions	03	03	06	07	07	10	-11	-14
Spatial orient	07	09	-01	-01	-04	-06	-21	-26[b]
Driver aptitude								
Driver battery I	30[b]	36[c]	19	23	-19	-27[b]	05	06
Driver battery II	22	26	-13	-16	01	01	-23	-28[b]
Road test score	10	11	-16	-19	-14	-21	-05	-06
Automotive info	08	09	02	02	-08	-12	04	05
Driving know-how	06	07	-06	-07	-16	-22	-09	-12
Personal history								
Age	21	25	21	25[b]	-03	-04	22	27[b]
Component[d]	-31[b]	-36[c]	-11	-13	-08	-11	-08	-10
Years of education	27[b]	32[b]	12	15	-32[b]	-46[c]	-02	-03
Martial status[d]	-08	-09	11	13	03	05	17	21
Pre-AASHO gr red[d]	15	18	01	01	-27[b]	-39[c]	45[c]	56[c]
Pre-AASHO sick call rate	01	01	16	19	13	18	09	11
Personality								
ASDB (transport)	16	19	14	17	-38[c]	-55[c]	-01	-01
Gen adj key (ADAS-7)	33[b]	38[c]	08	10	-14	-21	-08	-10
Mech key (ADAS-7)	00	00	26[b]	32[c]	-20	-29[b]	-01	-01
Attitudinal								
Compet. speed	10	12	12	15	-07	-10	13	16
Other users rdwy	16	19	08	09	-12	-19	18	23
Cops	-07	-08	-10	-12	-17	-24	04	05
Vehicle	-14	-16	13	16	-04	-06	05	07
Over-all	-03	-04	13	15	-15	-21	02	03
AASHO asgmt	12	14	12	15	-21	-29[b]	-02	-03
Reference								
Time spent at AASHO	02	03	-14	-17	04	05	-04	-05
Total mi driven AASHO	-10	-12	15	13	00	00	-17	-21

[a]Coefficients corrected for criterion attenuation, correction made assumed a reliability coefficient of 0.85.
[b]Significant at 0.05 level.
[c]Significant at 0.01 level.
[d]Point-biserial coefficients.

2. Intercorrelations between the two vigilance measures were low and not statistically significant.
3. The morale and general driver performance criteria showed low relationships with the vigilance criteria. Rated performance as a driver was related positively to driver morale.
4. The relative frequency of significant validity coefficients between the 39 predictors and vigilance criteria in two independent samples was at chance levels. When corrected for low criterion reliability, the average level of validity remained low.
5. In terms of promise in future validation studies, the Personality, Personal History, Driver Aptitude, and Perceptual Speed predictors seemed relatively more useful. The Cognitive, Physical, Psychomotor, and Attitudinal predictors seemed less useful.

The low between-shift reliabilities obtained in the present study suggest the need for a systematic study of retest reliability of vigilance scores over longer intervals of time than has yet been accomplished. Such a study would not only add to the present knowledge of the stability of the vigilance phenomenon but would have major implications for the appropriate amount of effort to be expended in the future development of vigilance predictors.

The lack of relationship between the two measures of vigilance has some significance for the selection of monitors providing the lack of relationship is generalized to other types of vigilance tasks. These results suggest that the behaviors involved in failing to detect critical signals and those involved in responding to false signals may have quite different psychological bases. It further suggests, in future attempts to predict vigilance performance, that the opportunities for occurrence of both errors of omission and commission be represented in predictor variables. Furthermore, these two types of errors should be properly weighted in the criterion measures by their relative consequences for the specific vigilance task involved.

The relatively greater success of the Personality and Personal History predictors suggests the presence of a motivational component in the vigilance criteria. This interpretation must be a tentative one, however, inasmuch as these relationships may be due to specific motivating conditions associated with driving at the Road Test and not related to general principles of vigilance.

If one could accept the assumption that the vigilance scores derived from the experimental task administered in this study were good estimates of the characteristic amount of vigilance shown by drivers in their normal driving duties, then the results indicate that the present U. S. Army operational driver batteries predict driver vigilance as well as any of the experimental tests tried.

In summary, the present study and others into the prediction of vigilance performance seems to be that in spite of large and fairly stable individual differences in detection proficiency, the highly specific nature of the criterion along with possible subject-task interactions serve to restrict the predictive utility of standardized psychological tests and measures. The present study indicates that the best practical test battery that could be assembled from the large number of generalized predictors used would be of marginal usefulness even though highly reliable criteria and very low selection ratios were possible. Thus, although the present study has failed to add materially to the establishment of valid correlates of vigilance performance, future study may show that specifically developed predictors closely approximating the criterion task in terms of relevant signal parameters (signal rates, intensities, intersignal intervals, and sensory modes) may result in improved prediction. Refined self-report inventories and biographical predictors may also prove useful.

REFERENCES

1. Adams, O.S., and Chiles, W.D., "Prolonged Human Performance as a Function of the Work-Rest Cycle." Human Factors Dep. Report ORD 273, Lockheed Aircraft Corp. (1961).
2. Bakan, P., "Extroversion-Introversion and Improvement in an Auditory Vigilance Task." Brit. J. Psychol., 50:325-332 (1959).

3. Broadbent, D. E., "Perception and Communication." Pergamon Press (1958).
4. Buckner, D. N., Harabedian, A., and McGrath, J. J., "Human Factors Problems in Anti-Submarine Warfare: A Study of Individual Differences in Vigilance Performance." Human Factors Research, Inc., Tech. Rept. 2, NONR 2649(00)(1960).
5. Dobbins, D. A., Tiedemann, J. G., and Skordahl, D. M., "Field Study of Vigilance under Highway Driving Conditions." Human Factors Research Branch, Tech. Research Note 118 (1961).
6. Edwards, A. L., "Experimental Design in Psychological Research." Rinehart (1960).
7. Garvey, W. D., Taylor, F. V., and Newlin, E. P., "The Use of 'Artificial Signals' to Enhance Monitoring Performance." USN. Res. Lab. Dep., No. 5269 (1959).
8. Hebb, D. O., "Drives and the Conceptual Nervous System." Psychol. Rev., 62:243-253 (1955).
9. Jenkens, H. M., "The Effect of Signal-Rate on Performance in Visual Monitoring." Am. J. Psychol., 71:647-661 (1958).
10. Jerison, H. J., and Wallis, R. A., "Experiments on Vigilance: One-Clock and Three-Clock Monitoring." USAFWADC Tech. Rep., 57-206 (1957).
11. Jerison, H. J., and Wing, S., "Effects of Noise and Fatigue on a Complex Vigilance Task." WADC Tech. Rept., 57-14 (1957).
12. Kappauf, W. E., and Powe, W. E., "Performance Decrement on an Audio-Visual Checking Task." J. Exp. Psychol., 57:49-56 (1959).
13. Loeb, M., and Jentheau, G., "The Influence of Noxious Environmental Stimuli on Vigilance." J. Appl. Psychol., 42:47-49 (1958).
14. McGrath, J. J., Harabedian, A., and Buckner, D. N., "Review and Critique of the Literature on Vigilance Performance." Human Factors Research, Inc., Tech. Rept. 1, NONR 2649(00) NR 153-199 (1959).
15. McGrath, J. J., Harabedian, A., and Buckner, D. N., "Human Factors Problems in Anti-Submarine Warfare: An Exploratory Study of the Correlates of Vigilance Performance." Human Factors Research, Inc., Tech. Rept. 4, NONR 2649(00)(1960).
16. McGrath, J. J., and Hatcher, J. F., "The Effects of Irrelevant Environmental Stimulation on Vigilance Performance." Human Factors Research, Inc., Tech. Rept. 6, NONR 2649(00) NR 153-199 (1960).
17. McGrath, J. J., "Human Factors Problems in Anti-Submarine Warfare: Cross Validation of Some Correlates of Vigilance Performance." Human Factors Research, Inc., Supplement, Tech. Rept. 4, (1961).
18. McNemar, Q., "Psychological Statistics." Wiley, 2nd ed. (1955).
19. Ramul, K., "The Problem of Measurement in the Psychology of the Eighteenth Century." Amer. Psychologist, 15:256-265 (1960).
20. Ray, J. T., Martin, O. E., and Alluisi, E. A., "Human Performance as a Function of the Work-Rest Cycle." Nat. Academy of Sciences—Nat. Research Council Pub. 882 (1961).
21. Uhlaner, J. E., "The Driver Vigilance Tester." Unpublished memo to Subcommittee on Human Reactions of the Special Studies Panel of the AASHO Road Test. USA TAGO (Feb. 1960).

Effect of Expressway Design on Driver Tension Responses

RICHARD M. MICHAELS, Bureau of Public Roads, Washington, D.C.

This study was an attempt to use the galvanic skin response technique to differentiate among the characteristics of four different expressway designs under different volume conditions. Six test subjects drove an 8- to 10-mi section of each highway four to eight times and events causing a speed or placement change were recorded. Only GSR aroused by the observed events was analyzed. The data were broken down by routes, volume, type of conflicts, and subjects. Using the analysis of variance it was found that there were significant differences among the designs on both design and traffic characteristics. Correcting for volume it was found that the Interstate design highway generated the lowest GSR rate relative to traffic interferences with the parkway and divided highway with only partial control of access generating the highest. On interferences related to design features, however, the Interstate design yielded the highest GSR rate. One reason for this reversal appears to be the higher speeds on the Interstate System.

This relation between GSR rate and volume was statistically reliable, showing a linear change up to volumes of 1,400 vehicles per lane per hour. For volumes greater than that, the GSR rate rose exponentially up to the maximum volume of 1,800 vehicles per lane per hour.

The results indicate that the GSR rate is directly related to the frequency of interferences and their relative predictability up to the point where the information load becomes excessive. At this point tension increases very rapidly. Also, the data indicate that modern highway design eliminates a large part of the major traffic conflicts. However, this reduction apparently leads to an increase in speed, which causes increased tension arousal from interaction with the physical characteristics themselves. Thus, GSR rate on highway interferences is higher on the highway of the most modern design.

• IN A PREVIOUS study (1) the galvanic skin response (GSR) was used to differentiate between two urban arterial streets. This study indicated that driver responses could be used as a means of discriminating between different types of city streets. The present study was an attempt to apply this technique to different types of expressway design to see if it were possible to discriminate among them and also to relate this to other types of highways.

Here the interest lay in two classes of tension-inducing events that may arise on expressways. The first are traffic interferences very similar to those encountered on urban streets. The second are those events associated with the interferences caused by geometric design features of the highways. There is considerable evidence for the superiority of expressway design over older or less highly controlled types of highway design. However, it is still a rather moot point whether there are differences among the various philosophies of design that are being proposed for controlled access highways. It was the basic aim of this study to differentiate among different designs using driver tension as a measure.

In the Washington metropolitan area, it was possible to find expressways of considerably different designs. These, in part, are distinguishable on the basis of age as well as their design features and speed. For this study, four different expressway

TABLE 1

DRIVING INTERFERENCES

Event No.	Name	Description
1	Instream vehicles	Conflicts caused by vehicles traveling in same direction.
2	Merging or crossing vehicles	Position or speed change caused by vehicles converging on test car.
3	Exiting vehicles	Position or speed change caused by vehicles diverging from traffic stream.
4	Gradient	Change in speed or position due to grade.
5	Curvature	Change in speed or position due to curvature.
6	Pavement changes	Position or speed change caused by variations in highway surface.
7	Shoulder objects	Position of speed change caused by shoulder objects such as cars or abutments.
8	Pedestrians	Changes caused by conflicts with pedestrians or animals.

designs were selected. One was built specifically to Interstate standards and is an Interstate route with a design speed of 70 mph. Another is a 15-year-old parkway with a design speed of 50 mph designed to standards that are considerably less rigorous in terms of both curvature and grade than are presently acceptable in flat or rolling terrain for Interstate highways. The third is an intermediate highway in terms of both age and design criteria. It is a 10-year-old urban freeway with relatively modern curvature and grade characteristics and a design speed of 70 mph. Its weakness lies in the substandard design of the acceleration and deceleration lanes. The fourth route was an expressway with geometric design quite comparable to that of the Interstate except that the magnitude of grade and curvature is somewhat higher than used for the Interstate route. The main difference is that it has only partial control of access, at least in the section under study. There are crossovers in the median as well as several at-grade intersections. Furthermore, there is a frontage road over a good portion of the route with commercial establishments being given access to the frontage road at a variety of points and the frontage road connections to the expressway are substandard. Thus, these four routes represent considerably different freeway designs although none of them may be considered extreme in any sense.

In general, then, the present study was an attempt to (a) differentiate among the four different types of expressway designs; (b) examine the tension responses generated on these expressways as a function of design characteristics, traffic interferences, and more generally in terms of traffic volume; and (c) relate these results to other types of highways.

PROCEDURE

Sections of the four test routes were chosen, all of which were approximately 8½ mi long. Generally, these were sections that were closest to the Washington area. Two of the routes had a relatively low volume; that is, less than 500 vehicles per hr in two lanes during daylight hours, and they had no appreciable peak hour. Consequently, only off-peak hours, running from 10 a.m. to 3 p.m. were studied. The other two routes, however, did have very definite peak periods and were, in fact, important routes for work trips into Washington. For these two routes, runs were made not only during the same off-peak hours as the other two but also during both the morning and evening peak hours. The times run on the latter two routes were adjusted to cover the maximum traffic load period. Volume counts were made on these two routes during the off-peak and peak hours before beginning the study so that the GSR data could be related to volume.

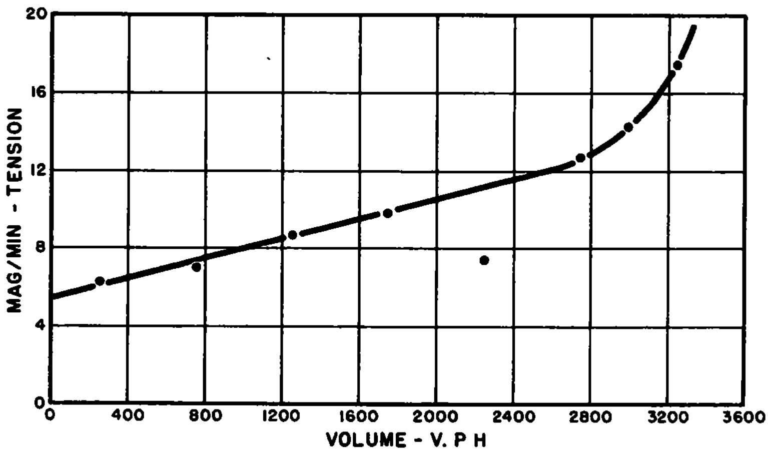

Figure 1. Effect of volume on tension responses.

Six test subjects were used. All were male ranging in age from 17 to 22 years. Two of the six had had previous experience in using the GSR and were fairly familiar with the plan of the study and the operation of the instrument. The six were broken into two teams of three drivers each.

The procedure followed in the present study was essentially the same as that used in the study of urban arterials (1). A standard passenger car with automatic transmission was used. Three people were in the test car during all the runs. Each member of this three-man team served as driver, observer, and data recorder. The observer sat in the front seat with the driver. Whenever there was a change in placement or speed of the test vehicle, caused by interferences from traffic or from the characteristics of the highway, the cause of the change was defined by the observer and was recorded on the GSR record by the data recorder. The interferences causing changes in venicle speed or position were coded into eight categories, four of which were traffic related and four of which were design related. The list of interferences are given in Table 1, Nos. 4 through 7 being related to highway features and the rest to traffic.

For the runs, electrodes were fixed to the first and third fingers of the driver's left hand. The sensitivity level of the GSR was adjusted to a point where a shock stimulus presented by the observer would give a full-scale deflection of the recorder pen. Once adjusted, the sensitivity was not changed while the particular driver was making his runs. The test driver drove the test route in one direction and then took a short break before returning in the opposite direction. Approximately 8½-mi sections were used, and the travel times ranged from 8 to 12 min. All six subjects drove each of the four routes 12 times for both off-peak and peak hours except for the two routes that had no peaks.

RESULTS

All the data were recorded on chart paper on which was not only the GSR information but also all the pertinent data about the route and the drivers. The only GSR data that were analyzed were those associated with the interferences shown in Table 1. Thus, this study concerned itself with only the galvanic skin response aroused by the specific, observable interferences. The basic measure of tension was defined as the magnitude of GSR per unit of time. This measure equalizes the routes for differences in either length or more generally running time. Furthermore, the use of this rate measure tends to make the distribution of the GSR more symetrical than when GSR magnitude is employed.

Of fundamental interest was the relationship between tension responses and the traffic volume. Over all four routes volumes ranged from approximately 300 to 3,500

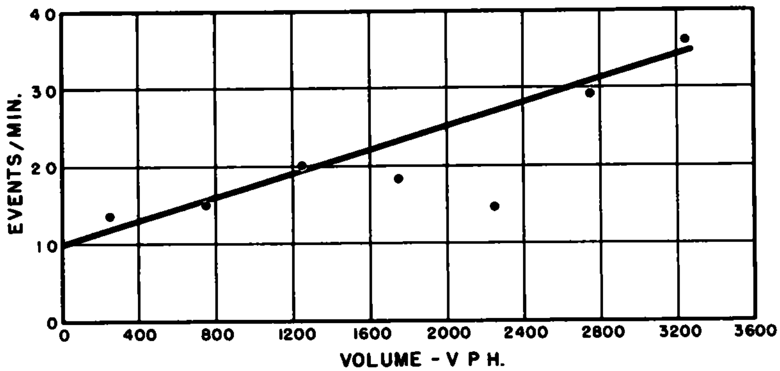

Figure 2. Effect of volume on the rate of occurrence of interferences.

vehicles per hour in two lanes. Data for all routes were combined according to volume. The curve of tension responses vs volume is shown in Figure 1. This curve includes tension responses only to traffic-caused interferences and not those caused by design characteristics. Thus, this relationship shows the effect of only traffic interferences on tension. It may be seen that there is a direct relationship between tension and volume. The relationship seems to be quite linear up to about 2,400 vehicles per hour in two lanes, and then the rise in tension appears to increase exponentially. These data were also analyzed by the subjects individually and the same general form of the curve was found for all.

A two-way analysis of variance was done on these data. In addition, an analysis of the trend of tension with volume was carried out. The summary is given in Table 2. The interaction term was found to be insignificant and was pooled with the residual. The results indicate a significant difference both among drivers and among volumes at better than the 0.01 level. In addition, the quadratic as well as the linear component of trend is significant at 0.01 level. Thus, the form of the curve shown in Figure 1 appears reliable.

One basic question in the use of the GSR concerns whether it is measuring something more than simply the frequency of occurrence of the interferences. Thus, if the same function defines the relation between interferences per unit time and volume as that which holds for tension and volume then the same results will be available simply by counting the number of changes in vehicle speed or placement. To examine this, the number of traffic interferences per unit time as a function of volume was calculated. The data are shown in Figure 2. An analysis of variance was carried out on the events per minute data the same as that for the tension responses. The summary is given in Table 3. Here, as in the previous analysis, differences among the two major variables are significant. The linear trend among the volumes is also significant at the 0.01 level but the quadratic component does not reach significance at this level. Thus, the straight line relation shown in the figure is the best fit to the data. From these two analyses it seems reasonable to conclude that the traffic interferences induce a greater behavioral response than is indicated simply by their frequency of occurrences. Thus, the GSR may be a behavioral measure of the operational efficiency of a highway, and also may be a measure of practical capacity of a highway.

Discrimination Among the Highways

The average magnitude of response per minute was determined for each subject, for each route, for the four traffic events during the off-peak hours. These data were subjected to an analysis of variance, given in Table 4. It may be seen that there are no significant differences between the directions (inbound vs outbound). There are significant differences, however, among subjects and also among the four routes.

Ordering the tension data according to highway, the highway built to Interstate standards generates less tension for each of the six drivers than do the other three highways.

TABLE 2

SUMMARY OF ANALYSIS OF VARIANCE ON TENSION CAUSED BY TRAFFIC VOLUME

Source of Variance	Sum of Squares	D F	Mean Square	F
Between subjects	2,034 38	5	406 88	25 70[a]
Between volume	2,865 04	5	573 01	36 20[a]
Error	1,535 76	97	15 83	—
Total	6,435 18	107	—	—
Linear trend	1,705 45	1	—	107 73[a]
Quadratic trend	117 72	1	—	7 44[a]

[a]Significant at the 0 01 level

TABLE 3

SUMMARY OF ANALYSIS OF VARIANCE ON FREQUENCY OF EVENTS CAUSED BY VOLUME

Source of Variance	Sum of Squares	D F	Mean Square	F
Between subjects	15 99	5	3 20	4 77[a]
Between volume	79 87	5	15 97	19 72[a]
Error	78 16	97	0 81	—
Total	174 02	107	—	—
Linear trend	70 15	1	70 15	86 60[a]
Quadratic trend	4 47	1	4 47	5 52

[a]Significant at the 0 01 level

However, this ranking includes differences in tension due to traffic volume. The urban freeway always carried, even during off-peak hours, three to four times as much traffic as did the other routes. To eliminate the effect of volume, a correction was applied using the data shown in Figure 1. All of the tension responses were corrected by multiplying them by a weight that was the ratio of tension at a volume of 500 vehicles per hour to that at 1,250 vehicles per hour. With the data so corrected, an analysis of variance was performed and, as before, a significant difference among the routes was found. Now, the ranking of the four routes was still reliable but the lowest level of tension was found on the urban freeway, followed by the Interstate route, parkway, and the freeway with only partial control of access.

The data were also analyzed to determine the effects of highway design interferences for the off-peak hours. Analysis of variance was done for the highway interferences just as for the traffic interferences. The results, given in Table 5, show significant effects among the drivers and routes.

Significant rank order among the highways was also found, which from the lowest to highest tension induction was urban freeway, parkway, freeway with partial control of access, and Interstate route.

Average Magnitude of Response for Each Event

Analysis was made of the average magnitude of GSR among the eight driving interferences. Rather than analyzing the average magnitude of GSR themselves, a rank test was employed. Such a test is weak but it avoids the necessity for meeting the distributional assumptions that would be required for stronger normal tests. The ranks were compared for each route with the test drivers considered as replicates. A summary of the four routes is given in Table 6 with the significance of the rank order. The Interstate route has a ranking among the events that is significant at the 0.01 level, and the parkway one that is significant at the 0.07 level. A further comparison was made on the rankings of the events on the four routes, combined. This was found to be significant at better than the 0.01 level.

The ordering among the eight different driving interferences indicates quite clearly that the traffic interferences consistently generate the highest magnitude of GSR. The highest average magnitude occurs for merging vehicles, and then secondarily, for both instream conflicts and exiting vehicles. Among the highway characteristics, the most tension inducing interference occurs with changes in the pavement characteristics followed quite closely by tension aroused during negotiation of curves.

Frequency of Occurrence of Events

The importance of the rankings of the average magnitude of the GSR previously described is meaningful in part according to the frequency with which these interferences actually occurred. Further analysis of the distribution of the occurrence of the interferences was carried out. The distributions for the four highways are given in Table 7. Here, the data for all subjects were combined. As the table shows, two interferences account for approximately 70 percent of all the driving interferences on all the routes: instream traffic interferences and negotiation of curves.

The differences given in the table indicate that on the urban freeway, instream interferences are considerably greater than the changes in curvature. This is to be expected from the relatively high volume of traffic that occurs even during the off-peak hours on this route. On the parkway, however, this pattern is reversed. This indicates the greater frequency and higher degree of curvature that occurs in this type of highway design. Further, this occurs even though the volume is greater on the parkway than on the remaining routes. This also indicates that the differences are due to design characteristics.

The eight interferences were broken into two groups: one involving traffic and the other highway features. The frequency of occurrence for the two groups is given in Table 8. Inspection shows that there is considerable similarity among the four routes. The major difference occurs in the parkway which demonstrates the sharp increase in the interferences due to highway curvature over and opposed to the other three routes.

The data on the distribution of traffic interferences given in Table 8 indicate that instream conflicts are the dominant type of interference that occur for drivers on freeways. All the routes are consistent during the off-peak hours running between 90 and 95 percent of all interferences. Also, Table 8 gives the proportion of all the observed events that are due to traffic interferences. The high-volume urban freeway has more than one-half due to traffic interferences while the Interstate highway has approximately one-quarter of its interferences caused by traffic.

TABLE 4

SUMMARY OF ANALYSIS OF VARIANCE OF TENSION RESPONSES CAUSED BY TRAFFIC EVENTS

Source	Sum of Squares	D F	Mean Square	F
Subjects	1,122 6	5	224 52	11 79[a]
Routes	468 0	3	156 0	8 19[a]
Direction	32 5	1	32 50	1 71
Routes and subjects	300 6	15	20 04	1 05
Direction and routes	118 5	3	39 50	2 07
Direction and subjects	64 7	5	12 94	—
Error	4,858 8	255	19 05	—
Total	6,965 7	287	—	—

[a]Significant at the 0 01 level

TABLE 5

SUMMARY OF ANALYSIS OF VARIANCE OF HIGHWAY FEATURES (4-7)

Source	Sum of Squares	D F	Mean Square	F
Subjects	2,416 4	5	483 3	26 6[a]
Routes	1,592 5	3	530 8	29 2[a]
Direction	95 4	1	95 4	5 2
Routes and subjects	1,564 6	15	104 3	5 7
Direction and routes	19 1	3	6 4	—
Direction and subject	243 1	5	48 6	2 7
Error	4,633 2	287	18 2	—
Total	10,564 3	255	—	—

[a]Significant at the 0 01 level

TABLE 6

RANK ORDER OF AVERAGE MAGNITUDE OF GSR GENERATED BY THE INTERFERING EVENTS FOR EACH ROUTE[1]

Rank[2]	Interstate	Urban Freeway	Parkway	Partial Control	All
1	2	2	2	3	2 (merging vehicles)
2	1	3	3	1	1 (instream vehicles)
3	7	1	1	2	3 (exiting vehicles)
4	6	5	6	8	6 (pavement)
5	5	6	7	6	7 (shoulder objects)
6	3	8	5	5	5 (curvature)
7	4	4	4	4	4 (grade)
8	8	7	8	7	8 (pedestrians)
Reliability	P<0 01	P<0 15	P<0 07	P<0 11	P<0 01

[1]For definition of events, see Table 1
[2]Ordering is from highest average GSR to lowest

Tension Induction on Freeways as Compared to Urban Arterials

Data were also available for two of the six subjects for the same urban arterial as studied previously (1). The data are, however, restricted to traffic interferences and do not reflect highway features. Table 9 gives a comparison of the high-type expressway, a parallel four-lane highway without control of access or grade separation, and the urban arterial. Tension increased greatly from expressway to the arterial; the ratios are shown in the last column of the table. These results indicate the superiority of controlled-access design in reducing these types of interferences.

DISCUSSION

The results of the study indicate that the GSR discriminates among different types of expressway design. Even though the actual differences among the designs of the four expressways used in this study were relatively small and all four expressways were in

TABLE 7

PERCENTAGE DISTRIBUTION OF INTERFERING EVENTS FOR THE TEST ROUTES—OFF-PEAK DATA

Event	Distribution (%)							
	Interstate		Urban Freeway		Parkway		Partial Control	
	In	Out	In	Out	In	Out	In	Out
1	21.0	24.0	48.4	51.9	29.4	28.3	30.7	31.3
2	0.8	0.7	2.4	1.2	1.7	1.1	2.6	2.2
3	0.5	0.3	0.4	0.9	0.8	1.4	0.9	1.0
4	23.9	26.8	11.2	12.9	8.0	11.3	17.2	18.0
5	37.4	39.1	26.3	22.3	43.7	41.9	37.2	38.8
6	11.9	3.9	5.5	5.2	6.2	6.2	9.0	5.5
7	2.3	1.8	0.2	0.8	0.5	0.7	1.0	0.8
8	0.2	0.2	0.1	0.4	0.8	0.5	0.6	0.2

TABLE 8

PERCENTAGE DISTRIBUTION OF INTERFERING EVENTS FOR HIGHWAY AND TRAFFIC SEPARATELY-OFF PEAK HOURS

Route		Highway Events (%)				Traffic Events (%)				Percent of Total That Are Traffic Events
		4	5	6	7	1	2	3	8	
Interstate	In	31.7	49.5	15.8	3.0	93.0	3.8	2.3	0.9	23.0
	Out	37.4	54.5	5.5	2.6	95.5	2.7	1.1	0.7	26.0
Urban Freeway	In	25.9	60.9	12.7	0.5	94.3	4.7	0.9	0.1	54.4
	Out	31.2	54.2	12.6	1.9	95.4	2.2	1.7	0.7	56.9
Parkway	In	13.8	74.9	10.5	0.8	89.8	5.2	2.4	2.6	35.9
	Out	18.8	69.7	10.3	1.1	90.5	3.6	4.5	1.4	34.2
Partial Control	In	26.7	57.7	14.0	1.6	88.4	7.4	2.5	1.7	35.1
	Out	28.5	61.5	8.7	1.2	90.2	6.3	2.9	0.7	35.5

good operating condition, there were significant differences among them in terms of tension responses. The differences relative to the two classes of driving interferences demonstrate the effects of the designs.

For traffic interferences, the urban freeway and the Interstate route were significantly less tension inducing than the other two highways. Actually, for the through driver both of these roads are quite comparable, for the urban freeway had geometric design characteristics that met Interstate standards over almost all of the study section. Its deficiencies as a highway had to do with marginal characteristics such as shoulders and ramps. Thus, when equated for volumes, the two routes are quite similar. The results indicate that as far as the frequency and magnitude of traffic conflicts, highways designed with complete control of access are clearly superior to those in which less

TABLE 9

TENSION GENERATED ON THREE DIFFERENT TYPES OF HIGHWAYS

Type of Highway	Tension (max/min)			Ratio of Tension on 3 Routes to Tension on Expressway		
	Driver A	Driver B	Avg.	Driver A	Driver B	Avg.
Controlled access	5.7	5.5	5.6	1.00	1.00	1.00
Uncontrolled primary	10.8	8.8	9.8	1.89	1.60	1.75
Urban arterial	13.9	23.5	18.7	2.44	4.27	3.34

rigorous designs are employed. There is little question that control of access eliminates much of the marginal conflict for the through driver. In this respect, it is interesting to contrast the Interstate route with one of similar design but with only partial control of access. The latter is consistently the most tension-inducing route. The major difference between this and the low-tension-inducing routes is an increase in the frequency of occurrence of conflicts with merging and exiting vehicles; that is, marginal interferences. This point is further shown in comparisons with the primary and urban arterial. These routes generate around 30 percent of their conflicts from marginal interferences whereas the high-type expressway generates less than 10 percent.

There is, moreover, a similar but more subtle interaction on the parkway. Here the tolerance of high curvature and gradient interact with the traffic interferences to increase the level of tension for drivers. As far as handling the conflicts in traffic, the driver has increased difficulties when he must also cope with rather large changes in the geometrics of the highway itself.

These relationships among the highways lend support to the hypothesis proposed previously (1) that one of the basic determinants of driver tension is the degree of predictability that exists in the driving environment. It is apparent from the present study that under high-volume conditions the driver is interacting with vehicles around him and must condition his performance to his expectations of what other vehicles are doing, and will do. In general, he does not have enough information to develop stable or reliable predictions about the activities of these other vehicles. In the case of a highway with only partial control of access, his problem is confounded by the increase in marginal activity, especially with both entering and exiting interferences involving large angular closing rates. Thus, increasing volume, increasing marginal activity, and finally, increasing variations in the highway itself all act to increase the complexity of driving. These, in turn, make it more difficult for the driver to develop stable predictions about his driving environment.

The results of the rankings of the routes for the highway features are rather anomolous. The Interstate route which operates well relative to traffic interferences generates the highest tension of all the routes on the highway interferences. The resolution of this paradox may well be due to differences in travel speed among these highways. Examination of the travel time for the test subjects indicated that the travel speed on the Interstate route averaged between 60 to 65 mph, whereas on the urban freeway it was near 50 mph, and on the parkway it was near 40 mph. Thus, there is a systematic difference among these roads in terms of the speed that drivers adopt.

The fact that speeds did increase would indicate that where traffic interferences are infrequent either because of low volume or by improved design, drivers compensate by traveling faster. In other words, drivers tend to make their speeds contingent on the perceived complexity of the driving situation. In effect, the design of the Interstate route permits the driver to increase his speed and he does so to the point where the characteristics of the highway (that is, curvature, grade, and pavement condition) begin to affect his operation of the vehicle. This would suggest that drivers adopt some kind of critical level of tension in driving.

In these terms, tension induced in driving may well represent one mechanism by which the driver can stabilize the system. That is, by driving at or near the speed at which tension responses increase sharply, the driver is able to determine qualitatively an upper limit to his control over the driving situation. This kind of criterion will be applicable to interferences due either to traffic or highway conditions, or both. When traffic conditions are such that the driver is subject to considerable stress, he will reduce his speed, thereby decreasing the frequency of tension inducing stimuli. When traffic is not a factor then he utilizes the highway characteristics, driving sufficiently fast to get information back from the road itself to give him a measure of performance.

The results of this study also bear on the problem of comfort and convenience. For many years it has been known that drivers' choices among alternative routes could not be accounted for on the basis of economy of operation or of time alone. It has been necessary, therefore, to postulate the additional factor of comfort and convenience. The basic problem with such a construct is to develop an operational definition that will make it measurable. Difference in tension responses on different highways may represent one avenue for resolving this problem.

The sample of data in this study indicates that there is twice as much tension generated on a highway that is an alternate route for an expressway than on the expressway itself. Furthermore, for traffic interferences, nearly 30 percent arose from marginal conflicts on the uncontrolled route whereas less than 10 percent arose on the expressway. For instream conflicts, however, there was little difference in tension generated; however, there were fewer of them on the expressway. Thus, there appears to be two major factors that account for the differences in tension between the expressway and the parallel, uncontrolled route: (a) proportion of marginal interferences; and (b) frequency of instream conflict. Such a breakdown suggests a logical distinction between comfort and convenience. Thus, what is called the "comfort" of a route may be defined as the tension caused by unpredictable conflicts. Route comfort may be considered in terms of the predictability of the interferences, and this appears to be measurable using the GSR.

Convenience may be defined as the degree of freedom that a driver has in setting the level of performance of his own system. Elements in the route that restrict the driver or force conformity to external controls would make that route inconvenient. Thus, for example, a wide variety of traffic control devices are generally predictable, but they force the driver to make control changes that may conflict with both the operation of his system and his driving objectives. Similarly, interaction with other vehicles in the traffic stream are frequently predictable (at least at moderate volumes) yet they restrict the driver's freedom of action. The relation between tension and traffic volume, shown in Figure 1, breaks sharply around 2,800 vehicles per hour or an average of 1,400 vehicles per lane per hour. This may represent the point at which the traffic situation becomes highly unpredictable. In terms of this discussion this would be the point where driving changes from being inconvenient to being uncomfortable.

Because the data show only small differences in average GSR among the instream events, it is quite possible that the frequency of occurrence of the events alone may be an adequate measure of convenience. Claffey (2) used such a measure in his studies of comfort and convenience, but made no distinction between the two factors.

It is difficult to determine the weighting of the two factors to fit some route choice equation. However, using the GSR as an over-all measure of both factors, the data in Table 9 show that the noncontrolled primary route was 1.75 times more tension inducing than the expressway and the arterial about 3.34 times. The subjective responses to the three routes reported by the subjects indicate that they subjectively evaluated the route in a direct but nonlinear relation with tension; that is, their dislike of a route increased more rapidly than tension increased. Considerable research is required to verify this relation and one determining choice among alternative routes.

The comparison of expressway designs with other types of roadways is quite clear in showing the superiority of modern highway design. These modern designs show that almost all traffic interferences are eliminated except those within the traffic stream itself. Thus, even under the highest volume conditions modern freeway design helps to restrict the kind of conflicts with which the drivers must deal to those that are easiest for him to resolve efficiently. However, this study also indicates that modifications in highway design alone may not necessarily increase over-all system stability.

REFERENCES

1. Michaels, R.M., "Tension Responses of Drivers Generated on Urban Streets." HRB Bull. 271, 29-44 (1960).
2. Claffey, P.J., "Characteristics of Passenger-Car Travel on Toll Roads and Comparable Free Roads for Highway User Benefit Studies." Public Roads, 31, 167-176 (1961).

Effect of Speed Change Information on Spacing Between Vehicles

RICHARD M. MICHAELS and DAVID SOLOMON, Respectively, Research Psychologist and Highway Research Engineer, Traffic Operations Division, Bureau of Public Roads, Washington, D.C.

The purpose of this study was to determine whether advance information on speed changes through a visual signal system markedly changes car-following behavior. A simple signal system placed on a lead vehicle categorized speed changes into four classes—two for acceleration and two for deceleration. The driver of the "following" vehicle was instructed to follow as if he were in heavy traffic and wished to prevent anyone from cutting in front of him. He was instructed to watch the signal system for advance information on the speed changes of the lead vehicle. A distance measuring system was placed in the following vehicle with which it was possible to measure headway continuously to within an accuracy of 5 percent. The headway was converted to digital form and encoded on a digital recorder. Speed of the following vehicle, together with the nominal speed and acceleration of the lead vehicle, was also recorded.

Speed changes in the lead vehicle were either 3 or 6 mph per sec and occurred in random order. The occurrence of a speed change was randomized over time so that the following driver did not know when or what change was to take place. The advance speed change information was presented at one of four time intervals before the onset of the speed change. A control condition was used in which no information was transmitted.

Results indicated a significant reduction in mean headway when advance speed change information was presented and that headway was a minimum when the advance information was presented approximately 1 to 3 sec before the onset of the speed change. At these optimum times the variability in headway was also significantly reduced. In addition, headways were found to be independent of speed; thus, time headways decreased almost linearly with speed over the range from 36 to 54 mph.

• VARIATIONS in the spacing maintained between vehicles has been attributed primarily to the drivers' reactions to changes in the speed of the preceding vehicle. On this basis, tests were conducted, with two- and three-car queues, in which a communications system was employed to transmit advance speed change information to the driver of a rear test car. Test data were analyzed to determine the effectiveness of the communications system—the test drivers' responses were studied to determine whether intervehicle spacing had been modified as the result of transmission of the advance speed change information.

This study was undertaken because intervehicle spacing is considered one of the more important factors affecting the stability of car-following patterns and thereby influencing the volume of traffic that can be moved on a highway. Analysis of the two-car test data indicated that use of a communications system, similar to the one employed in the study reported here, could increase the traffic-carrying capacity of a highway. From analysis of the three-car test data, it was noted that most of the potential effect of the communications system had been eliminated by interposition of a third car. With use of the communications system, a relation between advance warning time and the distance headways was noted for two-car queues.

Variability in headways was substantially reduced when the driver of a rear car had advance information on the speed changes. The variability noted in driver responses to information provided by the communications system indicates that the stability of intervehicle spacing is greatly influenced by fluctuations in the individual driver's psychological state. The behavior of drivers following in queues may be subdivided into two parts: (a) operation in a queue, which concerns the response of drivers in a queue to an imposed speed change by the vehicle ahead; and (b) steady-state operation; that is, the time and space relations that exist when all vehicles are traveling at about the same speed.

Recent research (1) indicates that variations in spacing between vehicles operating in a queue are determined primarily by the drivers' reactions to changes in speed of the vehicle ahead and, secondarily, by the distance between vehicles. When a change in speed is imposed in the lead car, the driver of the second car, in order to maintain his spacing, reacts to the change in speed and not to the change in distance. Thus, he changes the speed at which his car is traveling to eliminate any difference in speed between the cars. The stability of the operation depends, therefore, on the length of time elapsing from the lead vehicle's change in speed to its detection by the driver of the following car, as well as to his ability to modify the speed of his car.

As pointed out by Brown (2), estimates of speed changes ultimately depend on the driver's ability to detect changes in visual angle (the angle, at the eye of the observer, subtended by the boundaries of an object), which governs the time a driver requires to detect changes in the speed of the lead vehicle. Because of human limitations, small changes in visual angle and hence in speed are not detectable. Consequently, in normal car-following patterns a time lapse occurs between the initiation of a speed change in the leading car and its detection by the driver of the following car. To a large extent, much of the instability of operation in queues as demonstrated by other car-following studies could have resulted from the relative insensitivity of the drivers to small changes in visual angle.

The foregoing factors should also influence the behavior of drivers during steady-state following. Thus, the following distance that a driver will adopt during constant speed following should be in the range that maximizes his discrimination of lead-vehicle speed changes. In addition, his mean following distance should be contingent on the fact that he has no prior knowledge of the occurrence of any acceleration of the lead vehicle. Neither does he have any knowledge of the magnitude of that change of speed. (Display of brake lights or hand signals may warn of deceleration.) Therefore, the following driver may be expected to adopt a steady-state spacing to compensate for his uncertainty stemming from these two factors: his inability to detect small changes in visual angle and his inability to anticipate the change in speed.

This view of car following suggests two methods for improving the stability of following during both accelerative changes and in the steady-state. One method is to improve the ability of drivers to detect changes in visual angle. The second method is to provide the drivers of following cars with advance information about the magnitude of the speed change and its occurrence in time. The second method provided the basis for the study discussed in this article.

From the foregoing analysis several hypotheses are possible about the behavior of the driver of a car, when he is given information on the type and magnitude of each change in speed to be made in the lead vehicle.

First, the driver of the following car, by responding to this advance information, should be able to compensate for changes in speed in the lead vehicle by beginning his maneuver before the onset of the change. The degree of compensation effected should depend on the interval of time between the driver's receipt of the information and the onset of the speed change in the lead vehicle.

Second, because the driver of the following car does not have to rely on his ability to detect changes in speed, he will not have to maintain a spacing commensurate with his maximum ability for such detection. Consequently, it is reasonable to assume that the average headway during a constant speed operation would be less with a communications system than without it. (Headway is the time or space interval between two vehicles traveling in the same lane. For precise reference, the terms "distance headway" and "time headway" are used.)

Third, the variance in headway between cars in a constant speed operation should be decreased when communication is employed.

In summary, the purpose of this study was to determine whether, in a simple pattern of one car following another, intervehicle spacing could be modified when drivers were provided advance information on speed changes. The effects of this kind of communication were to be determined in both the steady-state following and in response to speed changes.

METHOD

Recording Instruments and Their Use

A stadimeter (a range-finding device) was used in this study to measure the distance headway between a pair of vehicles. The stadimeter operates on the same principle as the sextant in that two images are brought into coincidence by use of a rotating mirror. Because use of the stadimeter requires specification of some dimensions of the target whose range is sought, the dimension was marked by two brightly painted targets mounted on the rear bumper of the lead vehicle (Fig. 1). The mounting of the stadimeter in the second car is shown in Figure 2.

The stadimeter operator viewed the lead car through the ring sight on the right of the instrument. While looking at one target, he slowly rotated the mirror on the left of the sight by turning the crank on the left side of the instrument, until the image of the second target coincided with that of the first. The hand crank also was geared to drive a precision potentiometer so that the angular displacement of the mirror was translated into a voltage change. The distance in feet between the vehicles is inversely related to the angular rotation of the mirror. By use of a calibration procedure the voltage change was converted to the distance in feet.

The task of the stadimeter operator was to keep the two targets in coincidence during the run. For distances of more than 50 ft, tracking error generally was less than 5 percent, which was adequate for purposes of this study. A digital recording system, described by Hopkins (3), was employed to store the data. Headway readings were converted to digital form by use of a digital voltmeter, were read out, and were stored by use of a digital printer. The speed of the rear vehicle also was determined, digitized, and stored in the printer. An equipment operator in the rear car manually coded the following listed data into the printer: each speed change made by the lead vehicle, its speed at the beginning and ending of each maneuver, and the time each maneuver was started and ended.

Figure 1. Two-vehicle platoon; lead vehicle with overhead communications system and vertical targets mounted on rear bumper; rear vehicle which had fifth wheel and generator atop car driven by test driver.

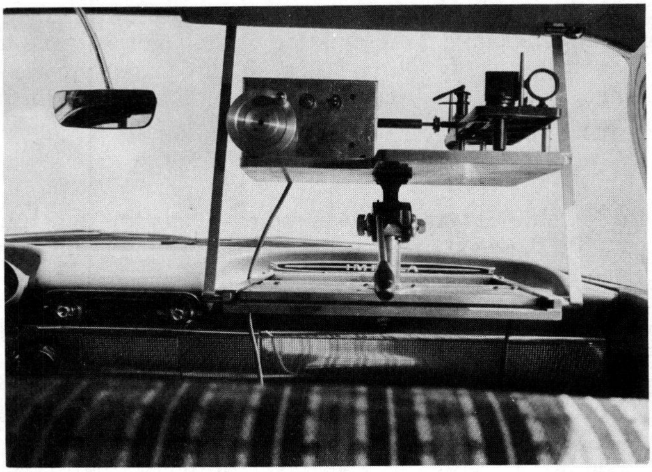

Figure 2. Stadimeter mounted in rear car used to measure headway between vehicles.

By means of radio equipment installed in the two vehicles, the lead car observer could notify the equipment operator in the following car what change of speed was to occur and when the change began and ended. This was done only when no visual communication signal was given. As the equipment operator used head phones, the driver of the following car could not hear these messages.

Four rates of acceleration were used for each series of maneuvers: +1, +3, -1, and -3 mph per sec. The interval between each maneuver in a series was either 15, 30, or 45 sec in duration. An automatic recycling timing system had been installed in the lead vehicle to specify the individual maneuver to be undertaken, the advance warning time (if any) to be signaled to the following car, the duration time of the maneuver, and the interval between the beginning of each maneuver in the series and the beginning of the next. By means of cue lights on the dashboard, the driver of the lead car was notified when to begin and end each maneuver. In general, the driver's control in making speed changes was accurate to within 5 percent.

The information display for the driver of the following car consisted of four traffic signal heads with white lenses, 8 in. in diameter, mounted above the lead vehicle, as shown in Figure 1. Each signal head represented one of the four possible speed change maneuvers. The size of the signal heads and the height at which they were mounted above the lead vehicle were dictated by possible conditions of grade, curvature, and length of queue that might be employed for any particular study to be made with this display.

Site of Study

A 7-mi portion of Interstate 70, located between Gaithersburg and Rockville, Md., and considered typical of a rural freeway, was selected as the study site. This freeway is a four-lane divided highway on which there is full control of access. Each of the four lanes, constructed of bituminous concrete, is 12 ft wide. Although the shoulders generally are 10 ft wide (8 ft of gravel and 2 ft of grass), a small part of the study site has gravel shoulders 12 ft wide. The dividing median is a grass strip 50 ft wide.

The speed limit at the test site is 60 mph and only a few vehicles were observed exceeding this limit. Typical of a rural freeway, the design speed for this section of the highway is 70 mph; maximum gradient is 3 percent, except for a length of 1,000 ft where the grade is 3.5 percent; and the maximum horizontal curvature is 1°.

The daily traffic volume on the section of the highway used for this study was about 10,000 vehicles. While the study was underway, daytime traffic averaged about 600 vehicles per hour or about 300 vehicles per hour on each one-way roadway—a relatively low volume of traffic for a freeway near a large metropolitan area. This low traffic volume and the high-type design characteristics of the highway were the principal reasons for selection of this study site. These factors made it possible to drive at a reasonably wide range of speeds for the required length of time with little interference to or from other traffic.

Procedure

Either two or three vehicles were used in the test runs for this study in which headways were measured for the rear cars, which were driven by test drivers. In addition to the test driver, the rear car carried the stadimeter operator (observer) and the equipment operator.

Drivers. —Seven drivers were used for the study. Four were summer employees of the Bureau of Public Roads; their ages ranged from 18 to 24 years; all had had at least two years of driving experience. The other test drivers were the experimenters conducting the study. All seven drivers participated in the test runs made with the two cars but only the four test drivers participated in the three-car test runs. To isolate any effects of possible bias, the primary analyses of the data collected from two-car tests were made only for runs by the four test drivers. Because analyses of the data indicated responses of all seven drivers to be quite comparable, information collected from all two-car tests was used for some of the subsidiary analyses.

Before the beginning of each test run, each test driver was given the following instructions: "Assume you are driving in rush hour traffic. Assume that vehicles are in the left lane beside you as well as behind you. Drive as you would in this type of traffic by keeping pace with the vehicle ahead so as to minimize the possibility of other vehicles weaving in front of you."

Two-Car Studies. —In the test procedure with two cars, the speedometer of the rear vehicle was covered and all the tail lights of the lead vehicle were disconnected for all test runs. The lead car carried out precise maneuvers and the headway was measured between the two vehicles.

Before the beginning of each test run, the study's signal system was explained to the test driver. He was told that when the signal lamp on the extreme left of the lead car was lighted a fast acceleration would be made, and that the next three signals would indicate fast deceleration, slow acceleration, and slow deceleration, respectively. The signal lamp was lighted before the onset of the speed change for a period of time determined by the preselected warning condition and remained lighted until completion of the maneuver.

A run included 16 speed changes—four repetitions each of maneuvers from 36 to 45 mph, from 45 to 36 mph, from 45 to 54 mph, and from 54 to 45 mph. Just before the start of each run, the test driver was also informed as to which of the five test conditions would be used: without communications or with communications at one of the four warning times (0, 1, 3, or 5 sec). For the "without communications" condition, the signal lamps were not used and the test driver received no information concerning the maneuver to be executed. When the run was made with communications, the signal system was used to indicate the magnitude of the speed changes to be made during each maneuver (+1, +3, -1, or -3 mph per sec), as well as to show the preselected warning time conditions.

All runs were started when both vehicles were traveling at a speed of 45 mph. The programing device was then activated in the lead vehicle and one of the four preprogramed speed changes was presented on the appropriate signal lamp. At the end of the first maneuver of each run, the lead vehicle was traveling at a speed of either 36 or 54 mph. Therefore, the second maneuver of a run required acceleration from 36 mph or deceleration from 54 mph. Thus, the test driver's uncertainty as to the speed change that would be presented was only half that he experienced when the next maneuver was to be made from a speed of 45 mph.

At the end of each run, another warning time condition was randomly selected; the test driver was informed of the new condition; and another run was executed by the two cars. This procedure was repeated until the test driver had completed five runs in succession, one for each warning condition. Each of the seven test drivers made five successive runs and the entire procedure was repeated four times for each of the five test conditions.

Three-Car Studies. —In the three-car studies, the signals for indicating speed changes and warning time were mounted above the first vehicle, which initiated all maneuvers, but the targets for headway measurement were mounted on the rear of the second car. The test driver operated the third car. Speedometers of both the second and third cars were taped over. The procedure for measuring the intervehicle spacing between the second and third cars was the same as that used for test runs with two cars. Runs were made with only three test conditions rather than five: without communications and with communications during which the warning time was either 1 or 5 sec. Only the four test drivers were used for tests with the three cars and test runs for each of the three conditions were repeated by each driver three times. The drivers of the second and third cars were given instructions similar to those given for the two-car runs.

ANALYSES

Choice of Headway at Constant Speed

Four independent variables were studied in the analysis of headway: (a) speed, (b) driver, (c) run, and (d) type of communications. Data were obtained for all 240 combinations of the four variables in the case of the two-car following situation. For the three-car data analysis, the 0- and 3-sec warning time conditions were omitted. Information was obtained from all possible combinations of the independent variables for the time intervals between maneuvers; that is, when the two vehicles were traveling at some constant speed. Samples of information, consisting of the record of speed and headway of both vehicles, were taken at 1-sec intervals by the digital recording system. To eliminate any time coherence among the sample points, additional samples were taken from recorded data at 5-sec intervals. In general, 10 to 15 samples were taken from each of the two speeds of 36 and 54 mph, which were maintained during four periods of time in each test run, and 20 to 40 samples were taken during the eight periods of time the speed was constant at 45 mph. To obtain a completely balanced block design for the analysis of variance, a final sampling of ten random observations was made for each of the three speeds of each run.

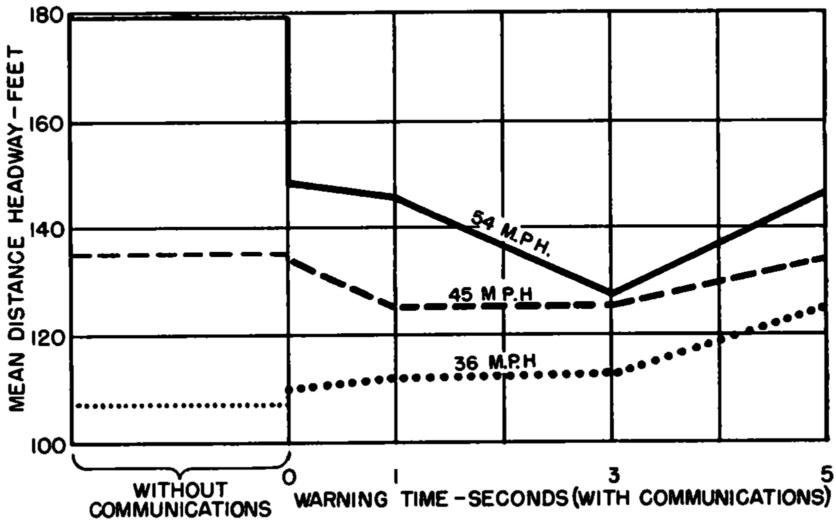

Figure 3. Effect of communications with various warning times on mean distance headway maintained at several speeds for a two-car platoon.

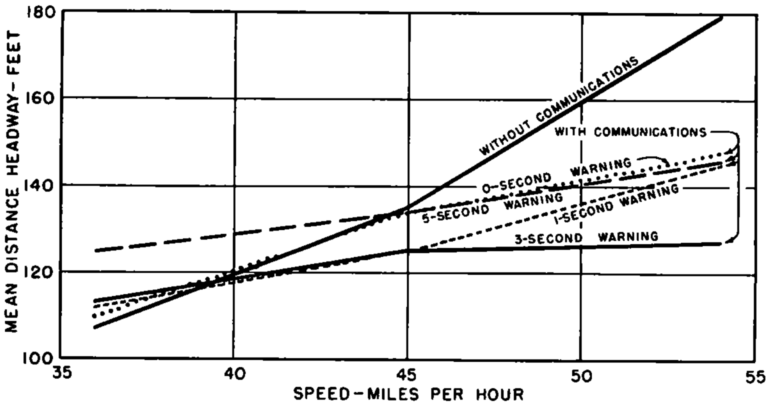

Figure 4. Effect of communications with several warning times on mean distance headway maintained at various speeds for a two-car platoon.

Analysis of Variance Data for Two-Car Runs

An analysis of variance was performed on the two-car data. Four main variables of three speeds, four drivers, four runs, and five communications conditions were used. For each of the 240 combinations of these variables, 10 headway measurements were employed, thus making 2,400 headway observations The analysis demonstrated that not only were the main variables significantly different at the 0.01 level, but also that all six first order, four second order, and the third order interaction terms were significant at the 0.01 level. As a check on the sampling procedure, an additional analysis of variance was performed on all the variable for one run (speed, driver, type of communications), and identical results of the analysis were obtained: all terms were significant at the 0.01 level.

Interaction of Speed and Warning Time. —For more detailed analysis of the effects of the communications system, data were separated on the basis of speed. At the highest speed of the runs, 54 mph, consideration of the data reveals a very significant reduction in mean distance headways when the communications system was used. This information is shown in Figure 3. With communications, the mean distance headways varied from a minimum of 127 ft to a maximum of 148 ft; without communications, the mean headway was 179 ft. True headway distances (from the rear end of the lead car to the rear end of the rear car) used for this analysis of the two-car test data were obtained by adding a constant of 10 ft to the recorded headway, which the stadimeter had measured from the dashboard of the following vehicle to the rear bumper of the leading vehicle. At the lowest speed used in the study, 36 mph, headways were no shorter with the communications system than without it. At the intermediate speed of 45 mph, the headways began to decrease with use of the communications system.

Warning Time. —Warning times had a considerable effect on the headways maintained as shown in Figure 3. With a 3-sec advance warning time at 54 mph, the drivers maintained minimum headways. At 45 mph, minimum headways appeared to have been maintained within the range of a 1- to 3-sec advance warning time. But at a speed of 36 mph, no differences in headway occurred when the warning time was less than 3 sec. However, with the longest advance warning time of 5 sec, headways maintained at all three speeds were much longer than those maintained with the 3-sec warning time. At 54 mph, headways maintained with a 5-sec warning time were about the same as those maintained with a 1-sec warning time and were 15 percent longer than those maintained with a 3-sec warning.

In Figure 4, the relationship of headway to speed is illustrated with warning time as the parameter. Without communications, distance headways increased sharply as speed increased. For each of the four test run conditions with communications, distance headways increased less as the speed increased. Most noteworthy is the fact that the shortest headways were maintained with the 3-sec warning time and, more importantly were practically independent of speed. Therefore, 3 sec may be considered the optimum warning time.

TABLE 1

MEAN DISTANCE AND TIME HEADWAYS MAINTAINED BY EACH OF FOUR DRIVERS AT THREE SPEEDS WITH AND WITHOUT COMMUNICATIONS IN A TWO-CAR PLATOON[1]

Speed (mph)	Communications Condition	Warning Time (sec)	Driver A Ft	Driver A Sec	Driver B Ft	Driver B Sec	Driver C Ft	Driver C Sec	Driver D Ft	Driver D Sec	Average Ft	Average Sec
36	Without	—	92	1.7	113	2.1	116	2.2	106	2.0	107	2.0
	With	0	111	2.1	120	2.3	111	2.1	97	1.8	110	2.1
		1	116	2.2	108	2.0	130	2.5	94	1.8	112	2.1
		3	114	2.2	116	2.2	127	2.4	94	1.8	113	2.1
		5	132	2.5	132	2.5	134	2.5	102	1.9	125	2.4
45	Without	—	114	1.7	165	2.5	149	2.3	112	1.7	135	2.0
	With	0	131	2.0	173	2.6	124	1.9	110	1.7	134	2.0
		1	122	1.8	127	1.9	131	2.0	119	1.8	125	1.9
		3	114	1.7	136	2.1	142	2.2	108	1.6	125	1.9
		5	129	2.0	152	2.3	148	2.2	107	1.6	134	2.0
54	Without	—	155	2.0	224	2.8	182	2.3	157	2.0	179	2.3
	With	0	142	1.8	189	2.4	131	1.7	129	1.6	148	1.9
		1	128	1.6	176	2.2	144	1.8	136	1.7	145	1.8
		3	117	1.5	137	1.7	143	1.8	112	1.4	127	1.6
		5	120	1.5	189	2.4	156	2.0	118	1.5	146	1.8

[1]Headways in two-car platoons were measured from rear-end of lead car to rear-end of rear car.

A further comparison of the relation of speed to headways maintained was made by converting the distance headways (Fig. 3) to time headways for each speed range. These respective time headways were plotted against speeds for each test condition. Figure 5 shows that when maneuvers were performed without communications the time headways increased at the highest speed: but for each of the four warning-time conditions with communications, time headways decreased with increased speeds. The lowest value of time headway was obtained from the data on the 3-sec warning time at the speed of 54 mph. The relation of time headway shown (Fig. 5) for the condition without communications and that shown for the 3-sec warning time is noteworthy. At a speed of 36 mph, the difference in time headways shown for the two communications conditions is not statistically significant, but at speeds of 45 and 54 mph the time headways obtained with a 3-sec warning time were significantly shorter than those from the condition without communications. At a speed of 54 mph this reduction was 30 percent.

Summary of Tabulated Data

A summary of all data collected during this study for the two-car runs is given in Table 1. Each entry represents the average of 40 observations of data collected for all four runs averaged together.

The time headways (given in Table 1) were calculated from the distance headways, as noted previously. For the calculation, it was assumed that the lead and rear vehicles were traveling at an identical speed of either 36, 45, or 54 mph. Because the drivers of the lead cars were extremely careful to maintain precise speed relationships, this assumption was close to the actual situation.

A large variability in response of the four drivers both to speed and the type of communications employed is evident from consideration of the data. Because of these significant differences in driver reactions, the averaged data shown in the summary column of Table 1 should be interpreted with extreme caution; these data, of course, represent a combination obtained from different populations.

Figure 4 shows the mean distance headways when the warning time was 3 sec were practically the same at all three speeds—between 113 and 127 ft; this range of only 14 ft is also shown in Table 1. The range in mean distance headways over the three speeds for the other four communications conditions varied from 21 to 72 ft; generally the same range was noted in the headways maintained by each driver. Test data also revealed that among the four drivers the relationship of mean time headways noted for conditions of no communications and the 3-sec warning time is consistent (Table 1). Although the

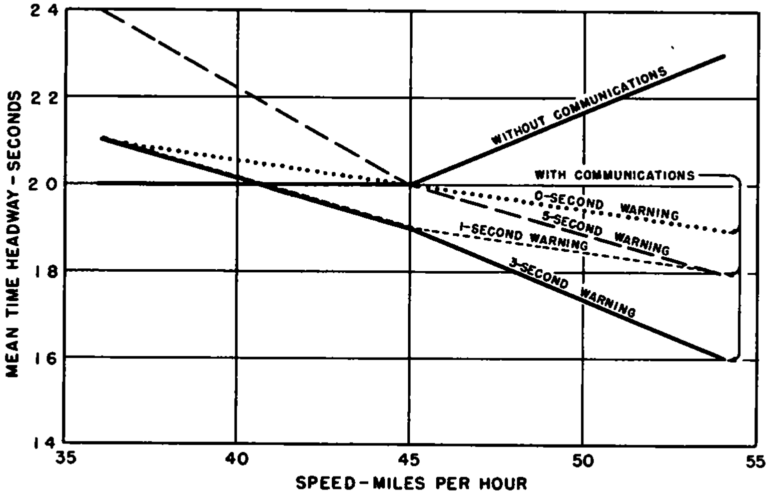

Figure 5. Effect of communications with several warning times on mean time headway maintained at various speeds for a two-car platoon.

TABLE 2

STANDARD DEVIATIONS OF DISTANCE HEADWAYS AND THEIR RATIOS WITHOUT AND WITH COMMUNICATIONS (3-SEC HEADWAY) FOR EACH OF SEVEN DRIVERS AT THREE SPEEDS IN A TWO-CAR PLATOON

Driver	36 Mph			45 Mph			54 Mph		
	Without Comm (ft)	With Comm (ft)	Ratio	Without Comm. (ft)	With Comm (ft)	Ratio	Without Comm. (ft)	With Comm (ft)	Ratio
A	16	16	1.00	24	21	0.88	24	15	0.63[a]
B	21	14	0.67[a]	25	17	0.68[a]	27	13	0.48[a]
C	78	16	0.21[a]	67	16	0.24[a]	67	24	0.36[a]
D	68	28	0.41[a]	56	30	0.54[a]	60	16	0.27[a]
E	15	10	0.67[a]	18	24	1.33	20	17	0.85
F	11	9	0.82	18	16	0.89	40	11	0.28[a]
G	14	8	0.57[a]	26	12	0.46[a]	29	13	0.45[a]
Median	—	—	0.67[a]	—	—	0.68[a]	—	—	0.45[a]

[a]Significantly different from 1.00 at the .05 level or less.

absolute values of the time headways for the four drivers differ significantly, the change in time headway as a function of speed is similar in that the time headways for the 3-sec warning time decreased sharply as the speed increased.

Communications

Data collected from runs made by the three experimenter drivers were added to the data for runs by the four test drivers for a further analysis of the variation in headways. Standard deviations of distance headways were calculated for each of the three speeds under two test conditions, without communications and with the optimum warning time of 3 sec. These calculations are given in Table 2. When data from the no-communications condition and the 3-sec warning time communication condition were compared, a reduction in standard deviation was noted for 19 of the 21 comparisons, and only 1 increase in standard deviation occurred. In most cases, the reduction was substantial and in 15 of the comparisons the differences were statistically significant. The median ratio of the standard deviation over all three speeds for all seven test drivers was 0.57, a reduction of 43 percent. In other words, communications reduced the variation in headway quite substantially.

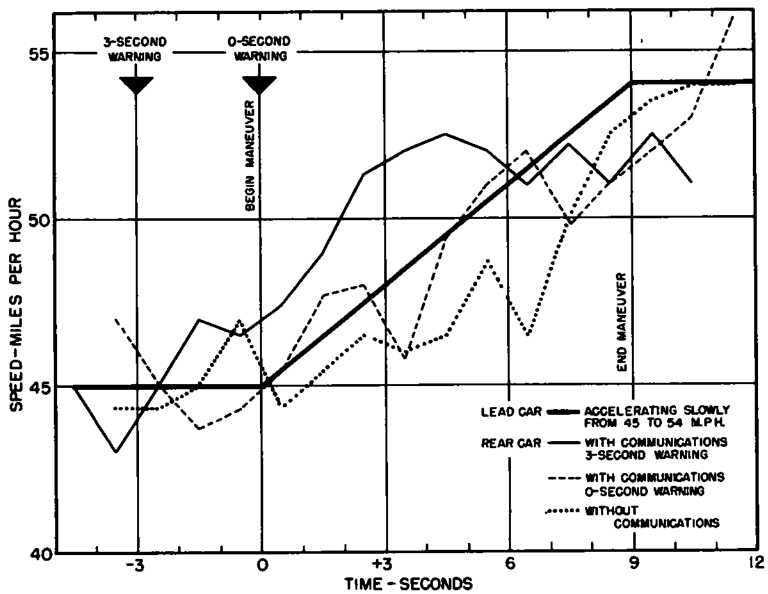

Figure 6. Typical example of rear car anticipating maneuver of lead car when 3-sec warning available in a two-car platoon.

Analysis of Speed Changes During a Maneuver

Another analysis of data obtained from test runs with two-cars was made of the speed changes carried out by the test drivers during the maneuvers. Although the limitations of the data-processing system prevented a precise analysis of the time course of the changes in speeds, it was possible to determine some of the effects of the communications system by the control responses of the test drivers. An example of typical responses is shown by the curves in Figure 6. When the speed change for the lead car was a slow acceleration from 45 to 54 mph at the rate of +1 mph per sec, the test drivers tended to respond so that the position of the rear vehicles changed from leading to lagging as the warning time decreased from 3 sec to 0 sec to a condition of no-communications.

This analysis also revealed some indication that the test or rear car drivers were using the warning intervals to begin the speed changes; such a response is shown clearly by the curve in Figure 6 for the 3-sec warning time. The drivers of the rear cars had closed on the lead vehicles during the initial part of a maneuver, when the optimum warning time of 3 sec was employed, then at some point toward the end of the maneuver had eased up on the accelerator thereby increasing the distance headways. The deceleration at the end of the maneuvers tended to show a great variability among the drivers and from one trial run to another.

Analysis of Data for Three Cars

For the portion of the study made with three cars, data on the effect of speed change information on intervehicle spacing were collected from only three test runs made by each of the four drivers.

For three cars, headways were measured from the rear of the second car to the rear of the third car; communications were transmitted from the lead car. The third or rear car was driven by a test driver.

An analysis of variance also was carried out on the data collected from test runs of the three cars. With one exception, all terms were significant at the 0.01 level: the third-order interaction term was significant at the 0.05 level.

TABLE 3

MEAN DISTANCE AND TIME HEADWAYS MAINTAINED BY EACH OF FOUR DRIVERS AT THREE SPEEDS WITH AND WITHOUT COMMUNICATIONS IN A THREE-CAR PLATOON[1]

Speed (mph)	Communications Condition	Warning Time (sec)	Driver A Ft	A Sec	B Ft	B Sec	C Ft	C Sec	D Ft	D Sec	Average Ft	Average Sec
36	Without	—	78	1.5	73	1.4	73	1.4	91	1.7	79	1.5
	With	1	90	1.7	71	1.3	97	1.8	88	1.7	87	1.6
		5	97	1.8	85	1.6	77	1.5	99	1.9	90	1.7
45	Without	—	92	1.4	100	1.5	84	1.3	107	1.6	96	1.5
	With	1	99	1.5	84	1.3	92	1.4	107	1.6	96	1.5
		5	110	1.7	103	1.6	89	1.3	103	1.6	101	1.5
54	Without	—	107	1.4	113	1.4	96	1.2	136	1.7	113	1.4
	With	1	109	1.4	97	1.2	91	1.1	116	1.5	103	1.3
		5	104	1.3	130	1.6	93	1.2	128	1.6	114	1.4

[1]Headways in three-car platoons were measured from rear-end of second car to rear-end of third car.

Analysis of three-car data showed that the mean headways were considerably less than those calculated for two cars, as can be seen by comparison of information given in Table 3 with that given in Table 1. In general, time headways were about ½ sec shorter for all communications conditions in three-car test runs. Moreover, the influence of the communications system was far less effective in causing the drivers to reduce following distance than it had been during the two-car runs.

With three cars and all three communications conditions, a small increase was noted in the mean distance headways as the speeds increased from 36 to 54 mph. However, decreases in mean time headways occurred both with and without communications; this decrease in time headways as speeds increased was larger when the test runs were made with communications. Table 3 contains headway data collected for three-car test runs.

When the interposition of a vehicle between the lead car and the rear car is considered, the 1-sec warning time for the three-car test runs appears to have had an influence on the headways maintained by the test drivers that is probably equivalent to the influence of the 3-sec warning time condition during two-car test runs. The summary column of Table 3 shows that with the 1-sec warning time a range of only 16 ft in distance headways occurred for 3-car runs between the speeds of 36 and 54 mph. When the 5-sec warning time condition was employed the range in headways increased to 24 ft, and when the condition was without communications it increased to 34 ft. The 16-ft minimum range with the 1-sec warning time is consistent with the lowest range in distance headways of 14 ft recorded at all three speeds for two-car tests with a 3-sec warning time condition.

Discussion of Data Analyses

Analyses of the data collected during this study indicate that substitution of an alternate information path for judgment of speed changes is possible, and that drivers are able to utilize a very simple coding scheme (communications system), at least in a two-car following situation. In other words, the driver of a car generally adapts his following distance according to the advance information he has about the changes in speed to be made by the lead car and his ability to make corresponding compensatory control changes in the speed of his own vehicle.

The major contribution of the signal system was its provision of information that permitted the test driver to begin his compensatory speed change before the onset of the speed change in the lead vehicle. Thus, a driver used the actual change in speed of the lead vehicle as a feedback on his speed control responses. This is shown by the curves in Figure 6.

Assistance from the communications system received by the test driver was least during an acceleration maneuver. Although limitations in the recording system precluded a complete analyses of the total effect of the communications system, some indication was noted of a lower rate of acceleration or deceleration with the display of speed change information than without it. However, considerable variation in acceleration or deceleration occurred during individual maneuvers, and this apparently resulted from the necessity for a driver to make visual angle discriminations and, more importantly, the predictions of future speed of the vehicle preceding his own. The experimental system employed in this study, of course, added nothing that a driver could use for such purposes.

The warning time (that is, the interval between display of the visual signal and the initiation of the speed change of the lead vehicle) was also observed to be an important factor in the following pattern adopted by the test driver in the rear car during constant speed operations. Analysis of the data showed that, dependent on the speed at which the test cars were traveling, minimum headways and minimum variance were obtained when the interval of warning time was between 1 and 3 sec. The warning time obviously was not employed solely as a reaction time but rather was used as a total response time of the system encompassing perception and translation into control and vehicle responses.

With the most favorable warning conditions, consideration of the analyses shows that spacing maintained between vehicles became independent of speed and indicated that another following system had been established by the driver. Although this system was speed dependent, the drivers employed a different information processing mode and adapted the headways to the remaining constraints on following—mostly random variations in speed between two vehicles.

Verification of Predictions Based on Hypothesis

On the basis of the hypothesis for this study, it was predicted that average distance headways between maneuvers would be less with communications than without. Analyses of the data from two-car tests indicated that this was true at the two higher speeds of 45 and 54 mph but not true for the low speed of 36 mph.

The prediction that the variability in headway would be reduced when the driver of the rear vehicle had prior information about speed changes to be initiated by the driver of the lead vehicle was confirmed by the analyses of test data.

Traffic Capacity of Freeway Lane.—Consideration of the data collected during test runs with two cars seems to indicate that a communications system could increase the traffic capacity of a freeway lane. As noted previously (Fig. 5), without communications the minimum time headways occurred at speeds below 45 mph and averaged 2.0 sec. If the time headways for a single lane of traffic averaged 2.0 sec for 1 hr, the total traffic volume would equal 1,800, which approaches the volume of 2,000 vehicles per hour that has been widely accepted as the possible capacity for a freeway lane. Few highways in the United States are known to carry a greater volume and other studies have shown that the minimum headways and maximum capacity usually are obtained when vehicles are traveling at speeds of less than 45 mph.

When communications were added, the speed-headway relationships changed markedly and the mean time headways decreased as the speeds increased. With the 3-sec optimum warning time, as shown in Figure 5, time headways of 1.6 sec were maintained at 54 mph, the highest speed used in this study. Were time headways to average 1.6 sec for 1 hr at 54 mph, the traffic capacity for a single freeway lane would exceed a volume of 2,200 vehicles per hour. Thus theoretically, utilization of a communications system, providing information similar to that of this study, would permit a one-third increase in the traffic capacity of a freeway lane. This increase was derived from the study data obtained when the test condition was without communications and the time headway at 54 mph was 2.3 sec, which would permit a volume of only 1,600 vehicles per hour. Therefore, what seems to be a fairly simple communications system would appear, by extrapolation, capable of generating a sizeable increase in the capacity of a freeway at the higher speeds. However, analysis of the three-car data does not allow such a conclusion. The addition of an interposed vehicle eliminated most of the benefits to be obtained from a communications system, as implied by the analysis of data from two-car tests.

The final column of Table 3 shows that without communications the average time headways between the second and third cars were considerably shorter at all three speeds than between the first and second cars with communication of a 3-sec warning time. Furthermore, with communication of a 1-sec warning and at speeds of 54 mph, the time headways in three-car runs were only 0.1 sec less than those maintained during the runs without communications. This elimination of most of the benefits, obtained by use of the communications system, with the interposition of a vehicle in a three-car queue may be attributed to several factors.

First, in a line of traffic a natural tendency exists to maintain stability of speed and spacing. Thus any speed change imposed by the lead vehicle may be expected to be compensated for by the drivers of successive vehicles as they perceive and thereby progressively reduce the effect of the speed change.

Second, if the driver of the third vehicle observed the speed change behavior of the first vehicle directly, he might very well receive as much advance warning as he would from the communications system. That such does take place has been suggested in a report by Forbes (4).

Third, automobiles in a line represent a very loosely coupled system, subject to considerable random fluctuations. A communications system such as the one used for this study should have a decreasing effect on the responses of the driver as the distance increases between the communications system and his vehicle. Any interposed vehicle prevents the following driver from directly coupling himself to the source. The driver, of necessity, must compensate primarily for the behavior of the vehicle immediately preceding his and secondarily for the behavior of those further ahead in the line. In essence, in the multiple car-following situation, the speed change display represents little more than a cue informing a driver that some change of speed will be made in the preceding line of traffic.

Variability of Drivers' Responses.—Another fact evident from analyses of these data is that a high degree of variability occurs both within and among drivers' responses. Considerable differences were noted in their responses concerning time relations and optimum following, minimum variance conditions, and at different speeds. Although the differences in mean headways with a 3-sec warning were quite small at all three test speeds, the analysis of variance showed a significant difference among speeds. As no systematic differences in variance occurred among the three speeds, it seems reasonable to conclude that the significance arises from inter- and intra-driver response changes from run to run. It would appear, then, that the driving system is greatly influenced by the moment-to-moment fluctuations in a driver's psychological state, as well as by his more stable behavioral characteristics. Sensitivity to such subtle qualities is not a characteristic of efficient man-machine systems.

SUMMARY AND CONCLUSIONS

From this study with two- and three-car queues, it was determined that the effect of the use of the communications system on the spacing between two vehicles varied with the speed at which they were moving; its use had little effect when the speed was 36 mph. but resulted in a large reduction in distance headway when the speed was 54 mph. However, when another vehicle was interposed, making a three-car queue, the communications system's effect on distance headway was nearly eliminated at all speeds. During constant speed operations, at any of the three speeds used, the variance in headways between the two cars was significantly reduced by the communication of speed change information to the test drivers. The transmission of this information approximately 3 sec before initiation of the speed change by the lead car permitted maintenance of the most uniform headways.

On the basis of data collected during the study, it is concluded that communication of advance speed change information from one driver to another is an extremely complex problem. Further, no simple or direct means exists for transmitting advance speed change information that will result in a universal or predictable modification of headway variance in the pattern of one car following another.

REFERENCES

1. Herman, R., and Potts, R. B., "Single-Lane Traffic Theory and Experiment." Proc., Symposium on Theory of Traffic Flow, Warren, Mich., pp. 120-146 (1961).
2. Brown, R. H., "Weber Ratio for Visual Discrimination of Velocity." Science, 131: 1809-1810 (June 17, 1960).
3. Hopkins, R. C., "Standard Electronic Units Interconnect to Provide Flexible Digital Recording." HRB Bull. 261, 44-49 (1960).
4. Forbes, T. W., Zagorski, H. J., Holshouser, E. L., and Deterline, W. A., "Measurement of Driver Reactions to Tunnel Conditions." HRB Proc., 37:345-357 (1958).

Driver Response to Amber Phase of Traffic Signals

PAUL L. OLSON and RICHARD ROTHERY, Respectively, Senior Research Psychologist and Physicist, Research Laboratories, General Motors Corporation, Warren, Mich.

Observations of motorist response to the amber phase of traffic signals obtained at five intersections, representing three speed zones, are presented. The data give an estimate of the probability of stopping for vehicles as a function of their distance from the intersection at the onset of the amber phase of the traffic signal. The results lend no support to a popular hypothesis; that is, that drivers tend to "take advantage" of a long amber phase by treating it as an extension of the green. The results of the study are compared with other investigations pertaining to amber phase lengths and implications of this work for the design of amber phases are discussed.

• IN A PAPER, Gazis, Herman and Maradudin (1) discuss in considerable detail a problem associated with the amber signal light in traffic flow. This problem arises when a driver, confronted with an improperly timed amber light phase, finds himself in the position of being too close to the intersection to stop safely and too far from the intersection to proceed and pass through it completely before the red phase commences. By means of a theoretical discussion and observational data, Gazis et al. present criteria for the design of the amber light phase which would eliminate such "dilemma zones"; that is, they derive the following formula for τ_{min}, the minimum amber phase duration:

$$\tau_{min} = \delta_2 + \frac{V_0}{2a^*_2} + \frac{W + L}{V_0} \quad (1)$$

in which

δ_2 = reaction and decision-making time of the driver;
V_0 = approach speed of the vehicle,
W and L = intersection width and vehicle length, respectively, and
a^*_2 = constant rate of deceleration for the case where the vehicle attempts to stop in front of the intersection (in practice this constant deceleration represents the maximum average deceleration to which it is desirable or practical to subject drivers).

To use Eq. 1, assumptions must be made concerning this deceleration as well as the reaction-decision time of drivers. Despite the uncertainties regarding these parameters, τ_{min} undoubtedly provides a reasonable approximation of an adequate amber phase duration. When it is used as a criterion, comparison of observed and calculated amber phase duration indicates that many light cycles are improperly designed even for fairly high decelerations (~16 ft per sq sec), and for reasonable reaction times (~1.0 sec).

There is a problem involving amber signal duration, which could probably be resolved by extending the duration of the amber phase so that it was at least τ_{min}. One major difficulty in adopting this procedure is the contention of many traffic engineers that drivers tend to regard long amber phases as extensions of the green. The inference from this contention is that drivers farther from the intersection may be tempted to continue where otherwise they would have stopped. Because of this, a greater error may be introduced in their judgments, increasing the probability of their being caught in the intersection during the red phase of the light cycle. Of course, even if this contention is valid it still does not constitute an adequate reason for presenting drivers with an insoluble problem during amber cycles, particularly if the vehicle code is not compatible with physical reality. In light of this contention the authors investigated the behavior of vehicle operators at normal intersections, making observations on those drivers caught near the intersection at the moment the amber phase commences to determine in particular whether the behavior of motorists in this situation actually does change with significantly different amber phase durations.

TABLE 1

PROBABILITY OF CARS STOPPING AS A FUNCTION OF THEIR SPEED AND DISTANCE FROM SIGNAL AT ONSET OF AMBER[1]

Speed (mph)	Distance from Signal (ft)		
	0.50[2]	0.80[2]	0.95[2]
30	100	120	135
40	160	190	210
50	225	275	300

[1] Data from Webster (2).
[2] Probability of stopping.

Another study related to this problem was made by Webster (2). In that experiment drivers approached a mock-up light signal at specific speeds. As the vehicle approached the light which was set on the green phase, the vehicle itself, at fixed distances from the stop line, triggered the light to the amber phase. From this admittedly artificial situation Webster was able to construct a table giving the probability of stopping at different speeds for particular vehicle distances from the intersection when the amber phase commenced (Table 1).

If the contention that long amber phases are regarded as extensions of the green is correct, then instead of one probability of stopping curve (P_S) for a given speed of approach, there should in reality be a family of curves, one for each significantly different amber phase duration.

In light of the preceding discussion it would seem important to determine whether driver behavior changes as a function of altered amber phase lengths. One way this problem might be investigated is to determine the probability of stopping as a function of the distance from a particular intersection for two different amber phase settings. However, because it would require some time, perhaps a very long time, for individuals to become aware of a change of the amber phase and alter their response (if they ever do), an alternate procedure was used This technique involved comparison of pairs of intersections as similar as possible in their physical characteristics but differing appreciably in amber phase durations. This latter approach has one disadvantage in that if the two resultant curves differed, it could not be legitimately maintained that it was due to the amber phase.

PROCEDURE

Two items of information were necessary to obtain the desired P_S curves: (a) the distance of the vehicles from the intersection at the beginning of the amber phase, and (b) whether each vehicle stopped or proceeded through the intersection. It is assumed that the speed distribution for a given speed zone does not differ appreciably from one intersection to another. The position of the vehicles was recorded photographically by setting a 35-mm camera to cover an area some distance back from the intersection and manually tripping the shutter as the light turned to amber. Simultaneously, a written record was made of the vehicles that were in this region, whether they stopped or not, and their identification as to make or other obvious characteristics. Cars that turned or were moving conspicuously slower than the bulk of the traffic were not considered. If the behavior of a driver was in any obvious way influenced by other drivers his vehicle was also eliminated. Thus, for example, if a car stopped, all others behind it were not recorded, even if there was an opportunity to change lanes. Only free-running, relatively open traffic was considered.

TABLE 2

FREQUENCY OF OCCURRENCE OF DIFFERENT SPEEDS DURING 5-SEC TIME BLOCKS OF A GREEN PHASE

Speed (mph)	No of Cars	Frequency				
		0-5 Sec	6-10 Sec	11-15 Sec	16-20 Sec	21-25 Sec
56 8	8	—	—	2	4	2
48 7	37	—	8	15	10	4
42 6	106	3	12	33	37	21
37 9	115	5	11	22	30	47
34 1	115	2	13	20	35	45
31 0	42	—	9	7	6	20
28 4	11	—	3	3	4	1
26 0	2	—	—	1	—	1
24 3	6	1	—	4	—	1
22 7	1	—	—	—	—	1
21 3	2	—	—	1	1	—
20 0	1	—	—	—	1	—
Total	446	11	56	108	128	143
Mean speed		37 3	38 0	39 0	38 8	36 7

Recordings were made generally in the afternoon, sometimes in the morning, covering all periods of the day except rush hours where the density of traffic was usually such that queues were created that would not clear during the green phase.

At each of the several intersections studied about 300 usable measurements were obtained. These were distributed among eight to fourteen 20-ft intervals back from the intersection. For the purpose of consistency the reference point along the road being studied, from which the measurements of vehicle position originated, was always taken from a point on a line with the paved edge of the intersected road. On the basis of the fractional number of vehicles that stopped in each of these intervals it was possible to plot the desired P_s curves, using the midpoint of each interval as the reference distance. The data in this form are displaced toward the intersection by an amount equal to the distance covered by the vehicles during the time required for the camera operator to react to the amber onset. Accordingly, a correction was made by shifting the curves back from the intersection by a distance equal to the product of the mean speed in feet per second and a reasonable reaction time. The value used for this reaction time was 0.15 sec as given by Woodworth and Schlosberg (3) for this type of stimulus.

Three speed zones were investigated: 25, 40, and 55 mph. To ascertain whether the traffic was moving at comparable speeds at the intersections to be paired, speed checks were made at each by means of a Simplex time productograph, recording the time required for a vehicle to move through a trap of a known length. Only freely moving vehicles which did not stop or turn were considered. Because it seemed reasonable that traffic would be moving at different speeds past the trap at different phases of the green cycle the speed data at the first intersection were classified according to time during the green cycle in 5-sec intervals. These data are given in Table 2. The small differences in the different classes were far short of significance as tested by the extension of the Median test described by Siegel (4). Because of this, only the mean speeds were considered in subsequent cases.

RESULTS

The first comparison was made between two intersections on thoroughfares whose speed limits were posted at 40 mph. In each case the mean speed was fairly close to the posted speed limit, being 38.0 mph in one case and 36.4 mph in the other. The differences between these two mean speeds is really quite small. For example, using Eq. 1, they would have a τ_{min} differing by approximately 0.1 sec.

At the time the measurements were taken both amber phases had been unchanged for more than a year. Both roads were four lanes wide with grassy medians over 100 ft wide. Table 3 gives the significant parameters; amber phase duration, intersection width, speed limit, and observed mean speeds together with the theoretical τ_{min} as calculated by Eq. 1 for the approach speed of 40 mph assuming maximum desirable decelerations of 12 and 16 ft per sq sec and reaction times of 0.75 and 1.0 sec. A car length was taken as 17 ft. Table 3 shows that neither amber is adequate for

TABLE 3

COMPARISON OF CHARACTERISTICS OF TWO INTERSECTIONS POSTED AT 40 MPH

Comparison	a_2^* (ft/sec²)	δ_2 (sec)	Mound at 11 Mile	Stephenson at Lincoln
Amber phase (sec)			4 15	2 90
Cross-street width (ft)			28	36
Mean speed (mph)			38.0	36.4
τ_{min}(sec)[1]	12	0 75	5 07	5 41
		1 0	5 32	5.66
	16	0.75	4.00	4 25
		1 0	4 25	4 50

[1] Based on speed of 40 mph

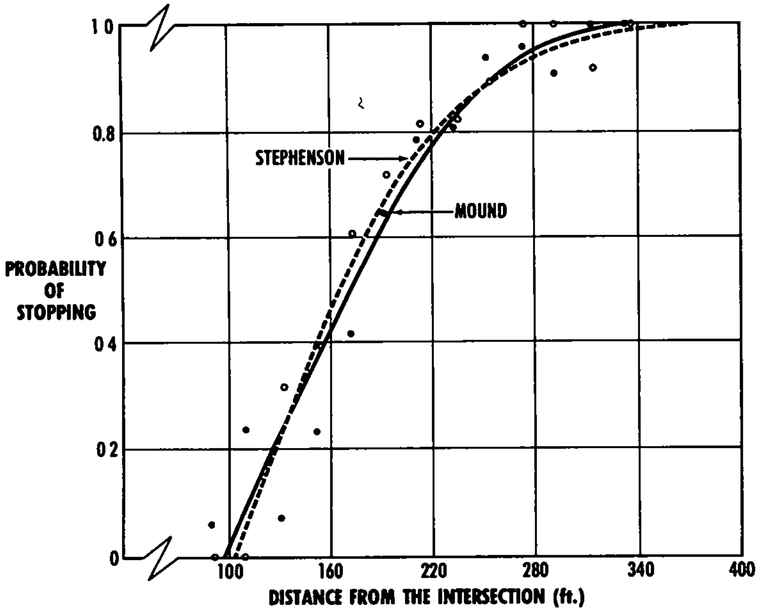

Figure 1. Comparison of probability of stopping for two intersections posted at 40 mph. Circles are points for Stephenson and solid dots for Mound intersection. Smooth curves are visual fit to data.

TABLE 4

PROBABILITY OF STOPPING DATA FOR TWO 40-MPH INTERSECTIONS

Mound				Stephenson			
Distance (ft)	No. Stopping	No. Not Stopping	P_S	Distance (ft)	No. Stopping	No. Not Stopping	P_S
92	1	15	0.06	94	0	17	0.00
112	5	16	0.24	114	0	20	0.00
132	2	26	0.07	134	7	15	0.32
152	5	16	0.24	154	8	13	0.38
172	8	11	0.42	174	11	7	0.61
192	13	7	0.65	194	18	7	0.72
212	19	5	0.79	214	23	5	0.82
232	13	3	0.81	234	20	4	0.83
252	16	1	0.94	254	27	3	0.90
272	23	1	0.96	274	29	0	1.00
292	20	2	0.91	294	21	0	1.00
312	23	0	1.00	314	12	1	0.92
332	11	0	1.00	334	18	0	1.00

reasonable decelerations or reaction times but the longer of the two is close to being satisfactory. Table 4 gives data for these two intersections, showing the number and percent of cars that stopped in each 20-ft interval. From these data the probability of stopping points was computed. These curves for both intersections are shown in Figure 1. The smooth curves represent a visual fit to the data.

TABLE 5

COMPARISON OF CHARACTERISTICS OF TWO INTERSECTIONS POSTED AT 25 MPH

Comparison	a^*_2 (ft/sec²)	δ_2 (sec)	Gratiot at Robertson	Gratiot at Church
Amber phase (sec)			4.75	3.00
Cross-street width (ft)			30	30
Mean speed (mph)			32.9	31.0
τ_{min} (sec)[1]	12	0.75	3.65	3.65
		1.0	3.90	3.90
	16	0.75	3.20	3.20
		1.0	3.45	3.45

[1] Based on speed of 30 mph.

TABLE 6

PROBABILITY OF STOPPING DATA FOR TWO 25-MPH INTERSECTIONS

Distance (ft)	Robertson No. Stopping	Robertson No. Not Stopping	Robertson P_S	Church No. Stopping	Church No. Not Stopping	Church P_S
77	0	36	0.00	0	15	0.00
97	2	36	0.05	2	34	0.06
117	9	18	0.33	19	16	0.54
137	10	16	0.38	22	7	0.76
157	25	15	0.63	27	6	0.82
177	23	5	0.82	34	2	0.94
197	51	2	0.96	34	1	0.97
217	85	1	0.99	18	0	1.00
237	—	—	—	26	0	1.00
257	—	—	—	17	0	1.00

It is apparent that no point along the P_S scale do the curves differ by much more than a car length, and at the higher percentiles there is an overlap.

A second comparison was made between two intersections on thoroughfares whose speed limits were posted at 25 mph. At the time the study was made, these signals had remained unchanged for more than four years. In this case both intersections were on the same four-lane street, approximately ½ mi apart. Table 5 gives the significant parameters of the two intersections. In this case, the actual mean speeds at both intersections are in excess of the posted limit. Because of this the data should be considered as a better approximation of what would be expected for an approach speed of 30 mph rather than 25 mph.

Table 5 shows that not only is there a significant difference between the two amber phases but the longer one is longer than would be recommended on a basis of an application of Eq. 1. Table 6 gives the data for these intersections and Figure 2 shows the P_S curves.

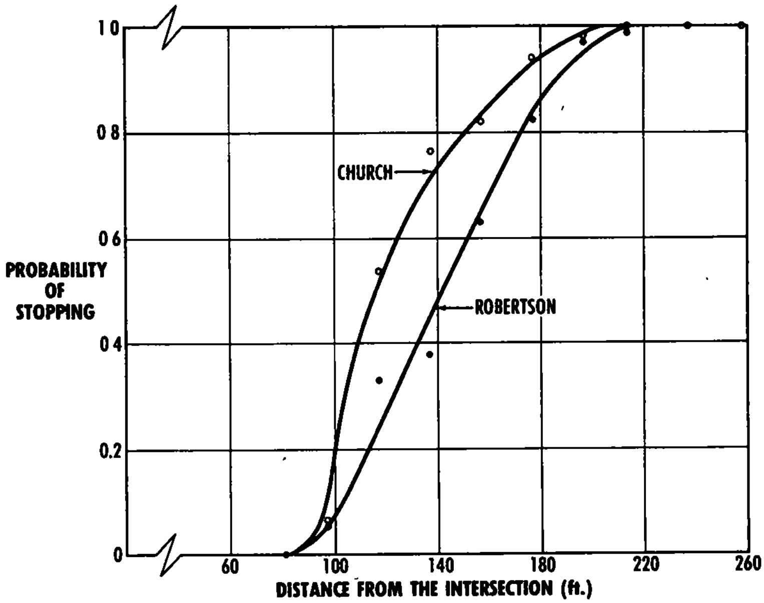

Figure 2. Comparison of probability of stopping for two intersections having mean speeds of approximately 30 mph.

The results of the first two comparative phases of this study indicate that driver behavior does not change significantly when faced with longer amber phases. For this reason the investigation of the higher speed zone was done at only one intersection, with no effort being made to pair it with another. Table 7 gives the significant parameters of the intersection and Table 8 gives the stopping data; the P_S curve is shown in Figure 3. Figure 4 shows representative P_S curves drawn for the 30- and 40-mph speed zones as well as the curve for the 50-mph intersection.

TABLE 7

CHARACTERISTICS OF AN INTERSECTION POSTED AT 55 MPH

Characteristic	a^*_2 (ft/sec²)	δ_2 (sec)	Value
Amber phase (sec)			4 20
Cross-street width (ft)			38
Mean speed (mph)			48 0
τ_{min} (sec)[1]	12	0.75	6.09
		1 0	6 34
	16	0.75	4 95
		1 0	5 20

[1] Based on speed of 50 mph.

ANALYSIS AND CONCLUSIONS

From Figures 1 and 2, comparing two sets of intersections, it would appear that there is no significant behavioral change in drivers associated with different amber cycle lengths. If the contention that drivers regard amber phases as extensions of the green were true, the P_S curve would be displaced a distance approximately equal to the difference in cycle length multiplied by the mean velocity of the traffic on the thoroughfare considered. For example, in the first comparison, a vehicle traveling at the posted speed limit of 40 mph would

TABLE 8

PROBABILITY OF STOPPING DATA FOR A 50-MPH INTERSECTION

Distance (ft)	No Stopping	No Not Stopping	P_S
221	6	58	0 09
241	13	26	0.33
261	13	21	0.38
281	17	20	0.46
301	25	15	0.63
321	31	10	0 76
341	25	5	0.83
361	24	9	0 73
381	21	2	0.91

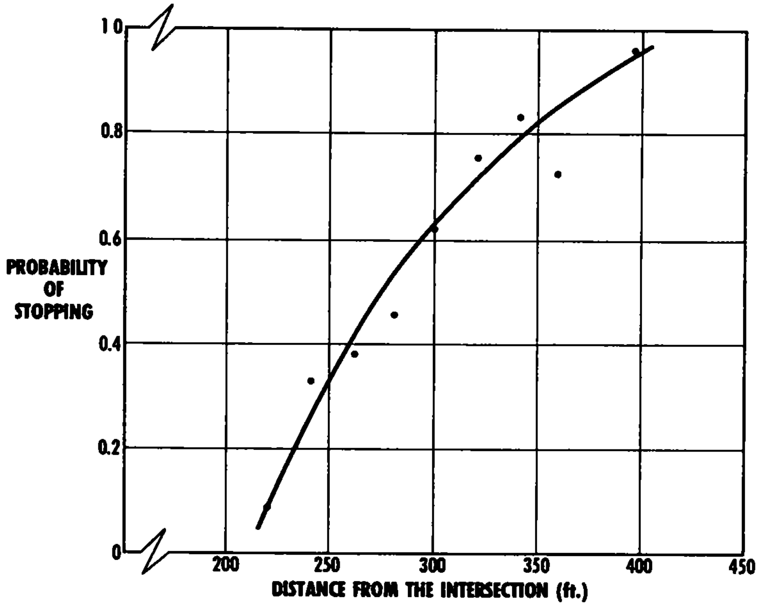

Figure 3. Probability of stopping for intersection where mean speed is approximately 50 mph.

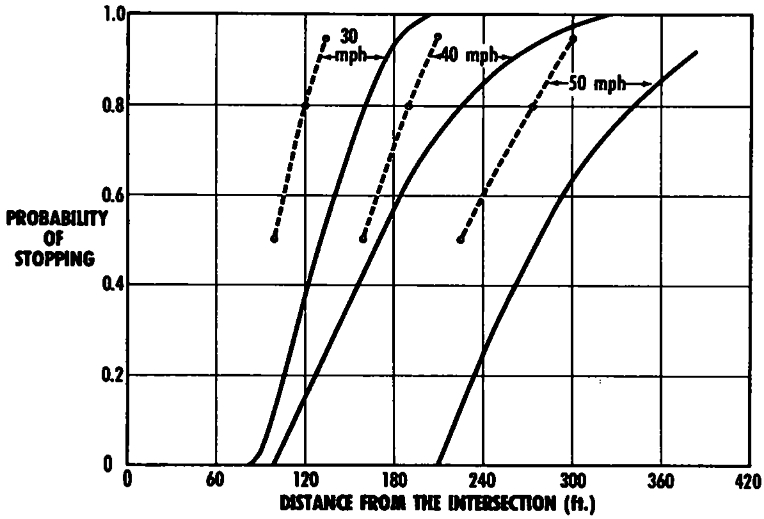

Figure 4. Representative curves for probabiliby of stopping for three speed zones. Dotted curves based on Webster data (Table 1).

travel approximately 80 ft in the 1.25-sec time difference between the two amber phase durations. The two curves of Figure 1 are displaced but a fraction of this distance. Similarly, in the second comparison, a vehicle traveling at the observed mean speed of 30 mph would travel a distance of 77 ft in the 1.75-sec time difference between these two amber phase durations. Again, the curves of Figure 2 are displaced but a fraction of this distance.

In comparing the representative curves of the three different speed zones of Figure 4, they are displaced from each other significantly for the different speed zones. The distance is approximately 40 ft at the 50th percentile point between the curves for the 30- and 40-mph speeds and approximately 105 ft between the curves for the 40- and 50-mph speeds, again at the 50th percentile point. In this figure Webster's data have also been plotted for comparison. For a given speed and distance his probability of stopping is considerably greater than for the same values in this investigation. For example, for an approach speed of 50 mph, Webster's stopping distance at the 50th percentile point is given as 225 ft. This would require an average deceleration of 17.7 ft per sq sec for drivers having a reaction time of 1.0 sec and would require an average deceleration of 15.8 ft per sq sec for drivers having a reaction time of 0.75 sec. These rather high decelerations can probably be attributed to the motivation and orientation of Webster's subjects.

In Figure 4 the stopping curve for the 50-mph zone is displaced from the stopping curves of the second comparison by approximately 105 ft at the 50th percentile level. From this displacement the apparent average deceleration to which drivers are willing to subject themselves is 12.9 ft per sq sec (assuming a 0.75-sec reaction time) at this level. Thus, the results seem to indicate that drivers allow themselves an added stopping distance for higher speeds to that they can stop comfortably with a deceleration in the range of 12 to 14 ft per sq sec.

The data in Tables 4 and 6 make possible an interesting comparison. By multiplying the length of the amber phase by the mean speed and subtracting the width of the intersection and the length of a typical vehicle, it is possible to calculate the average maximum possible distance a car, traveling at the mean speed, can be from the intersection at the beginning of the amber phase and still clear the intersection without accelerating. For example, using the data in Table 3, cars approximately 200 ft or more back from the intersection having the longer amber (Mound) could not have cleared in time. In the case of the shorter amber (Stephenson), cars approximately 100 ft or further from the intersection could not have cleared. Of the cars beyond this cut-off distance, 9 percent did not stop at the intersection having the long amber and 28 percent failed to stop at the shorter amber. In the case of the shorter amber light the dilemma zone is of considerable length. Indeed, assuming a reasonable desirable deceleration of 12 ft per sq sec and a fair reaction time of 1.0 sec, then the dilemma zone is about 100 ft. In comparison, the longer amber has a dilemma zone of 10 ft. It seems significant that of the 28 percent who did not stop at the shorter amber and who could not have cleared the intersection, 82 percent were in this 100-ft dilemma zone. One might conjecture that, if the shorter amber at Stephenson was extended to 4.2 sec, there would be approximately an 82 percent decrease in the number of vehicles that would not clear the intersection before the red phase. Furthermore, the fractional number of motorists who did not stop and who could not have cleared the intersection would then be essentially the same for these two intersections.

If driver behavior does not change as a function of amber phase durations, it should be possible to establish realistic amber phase settings on the basis of actual driver behavior. Thus one might decide that an amber phase should be of such a length that no more than perhaps 5 percent of the vehicle operators who do not stop when faced with the amber light do not clear the intersection before the red phase. Thus one could refer to a P_S curve for the appropriate speed, determine how far back from the intersection the 95th percentile point is, and use the following modification of Eq. 1:

$$\tau_{min} = \frac{A+W+L}{V_o} \tag{2}$$

in which

A = distance from the intersection at which the desired percentile occurs; and

W, L, and V_o = same as in Eq. 1.

For example, if the 95th percentile cutoff is used, the prescribed τ_{min} for the lower speed intersection (calculated at the actual mean speed of 32 mph) would be 5.25 secs, τ_{min} for the midspeed intersections (calculated at the actual mean speed of 38 mph) would be 5.39 secs and the τ_{min} for the high speed intersection (calculated at the actual speed of 48 mph) would be 5.57 secs. The small differences between these recommendations is noteworthy. It is probably feasible to use an essentially constant amber phase length for a large range of speed limits, making small changes only for unusually large cross-street widths.

This investigation of the behavior of motorists faced with the onset of an amber signal light has been a continuation of the theoretical analysis and observations reported by Gazis et al (1). This study was made to seek possible behavioral trends in this decision making problem that all too frequently occurs in every day traffic. The data are limited, mainly due to the extended effort required to obtain the kind of information necessary to make the comparisons presented. However, from these data the following conclusions can be drawn:

1. Driver behavior does not seem to change as a function of different amber phase durations.
2. The amber phases observed are too short as measured either by a criterion of driver behavior or a dilemma zone.
3. A constant amber phase of about 5.5 secs would be practical for a wide range of speed zones, with possible variations made to allow for extra wide cross-streets.

That drivers seem to react about the same to ambers of different duration is perhaps a result of confusion resulting from the fact that the average motorist simply does not know how long the typical amber phase is, a situation further confounded by the fact that there is no standard method of setting the length of the amber duration. Thus, the motorist, under these conditions may not try to react differently though the possibility exists that he would were ambers lengthened and standardized. Unless there exists a locale unknown to the authors where amber phases are characteristically longer than what appears to be "normal," this possibility cannot be checked out.

ACKNOWLEDGMENTS

The authors wish to thank R. Herman and J. B. Bidwell of the General Motors Research Laboratories for valuable discussions and constructive comments regarding this paper, as well as for their continued interest during this work. One of the authors (RR) also wished to express his gratitude to D. Gazis with whom he had several interesting discussions.

REFERENCES

1. Gazis, D.C., Herman, R., and Maradudin, A.A., "The Problem of the Amber Signal Light in Traffic Flow." Operations Research, 8:112-132 (1960).
2. Webster, F., "Progress of Work on a New Type of Controller for Traffic Signals on High Speed Roads." Road Research Laboratory, Research Note, RH/3634 (Dec. 1959).
3. Woodworth, R.S., and Schlosberg, H., "Experimental Psychology." Holt (1960).
4. Siegel, S., "Nonparametric Statistics." McGraw-Hill (1956).

Discussion

H.J. KLAR, Chief, Bureau of Engineering and Planning, New Jersey Division of Motor Vehicles, Bureau of Traffic Safety, Trenton—Although it is recognized that the motorist approaching a traffic signal at the beginning of the amber phase has a difficult decision to make, the writer fails to see the merit of using the same length of amber (5½ sec) regardless of vehicle approach speed.

Using the standard stopping distance formula ($S = \frac{V^2}{30f}$) on a level surface with f = 0.5 and allowing 2 sec for perception, intellection, emotion, and volition, one can readily calculate and obtain the following over-all stopping distances:

MPH	Ft
30	140
40	226
50	317
60	416

Calculating the distances traveled at the several speed, respectively, for 3, 4, 5, 6, and 5½ sec, the following are obtained:

Speed (mph)	Distance (ft) for 3 Sec	4 Sec	5 Sec	6 Sec	5½ Sec
30	135	—	—	—	248
40	—	240	—	—	330
50	—	—	375	—	413
60	—	—	—	528	484

If the commonly used "rule of thumb" for amber periods of 3 sec for 30-mph approach speeds, 4 for 40, 5 for 50, and 6 for 60 is applied and the over-all stopping distances for these speeds are compared with the corresponding distances traveled for the respective number of seconds, it is apparent that the "rule of thumb" values approximate or are on the conservative side of providing sufficient distance for a motorist to stop within the allotted distances if his attention is not diverted from the signal indications and assuming reasonably good friction between the tires and the pavement.

On the other hand, if 5½-sec amber periods were used for the 30-, 40-, and 50-mph approach speed locations, the distances traveled during this time interval would be considerably higher than needed. For 60-mph approach speed areas, the 5½-sec amber would be very good.

In the case of large intersections where the distance from the stop line to the collision point exceeds 60 or 70 ft, a short "All Red" period has been used to provide additional clearance time instead of increasing the length of the amber interval.

If the amber period is increased beyond what is normally needed for a given location, many drivers will ride the amber while some will conscientiously stop with the result that the rear-end collision potential increases.

At several selected locations throughout the State, a pre-warning device has been used to indicate to the motorist that the traffic signal will be red when he arrives at the signalized intersection.

This device normally displays an illuminated message "Signal Ahead" during the bulk of the green phase. "X" seconds before the red phase to that roadway, the sign message flashes alternately the words "Red" and "Signals Ahead." The alternating message continues to flash until the expiration of that red phase when it returns to the steady message "Signal Ahead."

In this way, fairly good information is given to motorists at all points in the signal sequence of operation at distances 500 to 1500 ft before the signal. Incidentally, the sign can be seen at much greater distances by motorists who are familiar with the operation.

It might be possible to help the motorist judge his distance from the white stop line by painting a yellow line transversely across the pavement at appropriate points commensurate with the approach speeds. The point at which the yellow line might be painted could be considered the "brake point." A motorist approaching a traffic signal would prepare to stop if he had not reached the "brake point" when the signal went amber. Conversely, if the motorist were between the "brake point" and the intersection, he would continue on through the intersection and would not be considered to be in violation of the signal, assuming, of course, that he was traveling near the normal approach speed.

The following table of distances is suggested for determining the "brake point":

Speed (mph)	Distance Before Intersection (ft)
30	140
40	240
50	360
60	470

Longer distances than necessary are used in this table for the higher speeds to provide a greater safety factor at these speeds. It is probably more likely for a motorist traveling at the higher speeds not to notice a traffic signal so soon because of the generally much greater spacing of signalized intersections. Another factor is that the vehicle brakes are more apt to cause a vehicle to swerve because the brakes have not been applied for some time, thereby requiring longer stopping distances. A third factor would be the greater difficulty of a motorist judging his distance from the intersection relative to his ability to stop or to continue on through.

To help the average motorist to understand the purpose of the yellow line, it might be well to erect a sign or signs at the end or ends of the yellow line bearing the message "Brake Point."

PAUL L. OLSON and RICHARD ROTHERY, Closure—The authors wish to reiterate that the main purpose of the study was to provide data on actual performance of drivers, with the hope in mind that amber phase durations could be adjusted to suit human performance. On the other hand, the writer quotes a frequently employed "rule of thumb" for determining stopping distances. The authors have two comments to make regarding this rule: (a) a rule of thumb, based on what seems reasonable to expect from humans, can hardly be used as an argument against actual measurements of what they do; (b) this rule of thumb assumes an average deceleration of approximately 16 ft per sq sec. On the basis of the study this assumption appears to be unreasonable. More specifically, another study (1) has shown that drivers in a variety of traffic situations brake with a deceleration of 16 ft per sq sec or more less than 1 percent of the time.

The common assertion that when the amber period is increased beyond what is normally provided, many drivers will ride the amber while some will conscientiously stop with the possible result that rear-end collision potential increases was subject to specific scrutiny in the study. It will be recalled that no significant differences in the location of the end points of the probability of stopping curves were found when comparing intersections having the same speeds but different amber phase durations. This is the only evidence the authors know of that bears directly on this question and it stands in direct refutation of the popular notion.

There seems to be some confusion resulting from the example used in trying to indicate how the probability of stopping curves could be employed to set amber phases. The figure of 5.5 sec results from selecting a cutoff at the 95th percentile. The selection of percentile cutoffs is completely arbitrary. The important point is that information such as that obtained from probability of stopping data makes it possible to estimate what percent of the drivers who elect to proceed through the intersection will not clear the intersection before the signal turns red.

The amber brake line suggested by the writer would undoubtedly provide added information. It might possibly improve the situation. However, for reasons indicated earlier, it certainly should not be based on a deceleration as high as that suggested.

In addition, there exists the possibility that the use of such a stop line would create unique problems under conditions where the road surface is slippery or to drivers moving slower than the speed limit. This could be subject to investigation and probably should be before such a system were widely employed.

The all-red clearing period that is being used in some parts of the country is potentially valuable and might be one solution to the amber light problem. However, if it is to provide a legitimate clearing phase a reinterpretation of ordinances would be required in many areas so that persons in the intersection during the all-red period would not be in violation.

REFERENCE

1. Olson, P. L., and Bauer, H. J., "Deceleration Forces in Normal Driving." General Motors Research Laboratories Tech. Memo., pp. 24-611 (1960).

Influence of Mental Set and Distance Judgment Aids on Following Distance

STUART WRIGHT and ROBERT B. SLEIGHT, Respectively, Program Director and President, Applied Psychology Corporation, Arlington, Virginia

Little information is presently available on the relation between various driver characteristics and following distance. Using a photographic technique for measuring distance between vehicles, two experiments were designed to measure (a) the effects on following distance of driver set, or general attitude toward the particular driving situation, and (b) the ability of drivers to maintain specified following distances, both with unaided vision and with two simple judgment aids. When drivers were asked to drive on a newly constructed highway not yet open to traffic under each of three sets—emergency, habitual, and maximum safety—at speeds of both 30 and 50 mph, the results indicated that drivers believed they habitually drove with maximum safety, as far as actual following distances were concerned. The distances obtained under the "habitual" set were found to be somewhat greater than those found in regular traffic on similar highways by previous investigators.

Both aids to distance judgment substantially reduced errors made with the unaided eye, at both 6- and 8-car lengths and a speed of 40 mph.

• FAULTY following distance has been held to be a major, or a contributing, factor in over one-third of American motor vehicle accidents (6). The same poor judgment that in some cases produces collisions may be responsible in other circumstances for disturbances in the even flow of vehicular traffic. Thus, vehicle separation, or the bumper-to-bumper separation of two vehicles traveling in the same lane in the same direction, is a matter of prime interest to those concerned with optimum utilization of highway space.

Freeborn and Orchard (4) conducted a study in which drivers were asked to maintain minimum safe following distances. Forbes et al. (3) used both open highway and tunnel conditions to measure the effects on individual following distance of such factors as acceleration, deceleration, curves, grades, and visibility. Subjects were told to drive "closely but safely as if anxious to get home in heavy traffic" (3, p. 346). Apart from these two studies, following distance behavior on the open highway as an element of individual driver psychology has not previously been studied, in terms either of external factors or of driver characteristics. Mass data are available on environmental factors that affect following distance, such as traffic volume and speed, grades, lateral interferences, curves, and kind of highway, in such source books as "The Highway Capacity Manual" (2). A useful review of other approaches to the study of following distance on the open highway is found in Chandler, Herman, and Montroll (1).

The study reported herein was undertaken to investigate two aspects of following distance vehavior: (a) changes in following distance associated with various mental sets and (b) use of visual aids in maintaining accurate following distances. The mental sets studied were habitual, emergency, and maximum safety driving. These terms are explained more fully later.

The distance judgment aids utilized either timing or the visual fusion phenomenon.

METHOD

To eliminate error resulting from interference by other vehicles the lead car and following cars were the only vehicles present. Speed was controlled by the driver of the lead car, and following distance was controlled by the subject in the following car, according to pretrial instructions.

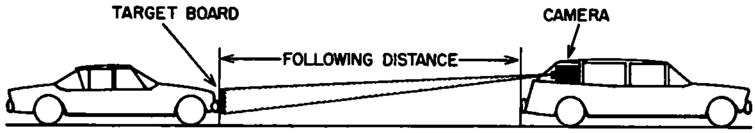

Figure 1. Data collecting situation, illustrating following distance and motion picture camera position.

Distance was measured by an adaptation of the Forbes method (3) using a motion picture camera mounted in the rear window of the lead car and aimed at a target board mounted on the front bumper of the following car, as shown in Figure 1. A frame-by-frame analysis of the following distance was made after the trials; therefore, no feedback information was given the subjects during the data collection.

Previous experimentation had shown that when film projection conditions were standardized, measurements having an average error of less than 2 percent could be obtained for following distances up to 200 ft by using photographs of the target board, then measuring the length of this strip on the projected film image.

The highway used was a 3-mi section of the Baltimore (Maryland) Tunnel Thruway—Northeastern Expressway, which had not been opened to the public. This was a two-lane highway, marked with lane lines. There were no lateral interferences, very little curvature, and adequate sighting distances at all times.

Subjects

The subjects were 20 male and 6 female adults, representing approximately the proportions of each sex in the three age groups (21-26, 35-40, 50-55) of the driving population.

All subjects were screened in terms of age, education, driving experience, occupation, and experience with the type of car and transmission to be used in the experiment. Those selected were tested for 12 visual abilities, for brake-response time, and for attitudes toward driving (5).

No subject admitted having had an accident in which there was loss of life, or damage exceeding $500. Mean driving experience was 14.3 years, and the average of total miles driven was 165,000. These data are given in Table 1.

Socioeconomically, the subjects were quite diversified. Among the occupations represented were housewife, policeman, college student, taxi-driver and accountant. Mean number of years of education was 12.3, with a spread from 8 to 18 years, the majority did not go to college.

Apparatus

The measurement apparatus consisted of a 16-mm motion picture camera mounted over the back seat of the lead car and focused on a 5-ft target board fastened to the front bumper of the following car. The camera was run at a constant rate of 8 frames per sec.

The automobiles were late-model automatic transmission sedans of American manufacture.

TABLE 1

SUBJECT CHARACTERISTICS

Characteristic	Mean	S.D.
Age (yr)	34.62	10.29
Education (yr)	12.27	2.85
Driving experience (10,000 mi)	16.51	19.74
Vision:		
Acuity:[1]		
Both	18.83	5.65
Right	23.04	9.51
Left	23.87	12.36
Phoria:[2]		
Vertical	-0.06	1.60
Lateral	0.97	2.23
Stereopsis[3]	6.87	2.46
Brake response time (sec)	0.425	0.036

[1] Snellen equivalents may be obtained by writing 20 above score.
[2] Zero indicates complete muscular balance.
[3] High scores indicate good stereoscopic ability (range 0 to 9).

Figure 2. Visual aid stimulus board for distance judgments.

Two special pieces of equipment were developed for this study, both mounted by brackets to the bumper of a car. The first, used in the photographic measurements, was a 5-ft white rectangle mounted on a matte black finish board.

The second, a special stimulus board used in estimating following distance, consisted of two sets of stimuli utilizing the visual fusion phenomenon, as shown in Figure 2. One set was comprised of four pairs of reflectorized yellow bars, 1 by 5 in., mounted in vertical parallel pairs. The spaces between the bars were $\frac{1}{32}$ in., $\frac{2}{32}$ in., $\frac{3}{32}$ in., and $\frac{4}{32}$ in.

The other set of stimuli consisted of four Landolt "C" rings having gaps equal to the separations of the parallel bars. The gaps were oriented randomly.

Both sets of stimuli were mounted on the same matte black finish board, which in turn was mounted on the rear bumper of the lead automobile.

Procedure

Phase I. Mental Set.—An attempt was made to influence the subjects' mental set through verbal instructions. Three sets of instructions (habitual, emergency, and maximum safety) were given at various stages of the experiment. The following standardized wording of the instructions were used:

Habitual: In your first test run, you will simply be asked to follow this lead car at whatever speed he sets. Just travel along behind him as you would ordinarily do if you wanted to drive at about the same speed. This is all there is to it. This run will be made four times in succession, at two different speeds.

Maximum Safety: We are now going to make a run just as we have already done, with one exception. You are to suppose that you wish to drive as safely as possible while at the same speed as your friends in the lead car. You have your family in the car and you are going to a picnic. One older person is very nervous about riding in traffic, and there are a couple of very active and noisy children. You are in no hurry whatever, and wish to be entirely sure of your safety. Do not pass the lead car, and be sure to travel at about the same speed.

Emergency: You will now make a run just as you have already been doing, with one exception. Imagine this time that you are in a situation where you must get where you are going just as fast as you possibly can, but you are prohibited from passing the car in front of you. For instance, suppose that you are in an evacuation from the city, and you are in a mass of traffic. The main idea is to get as many cars past the city line as possible, in as short a time as possible. You have been requested to drive as close to the car in front of you as you possibly can, without endangering your car or yourself, and without causing a traffic tie-up by a collision.

(After the second run, further instruction was given:) You will be repeating these runs, and others, several times. Vary your driving in any way you wish from time to time. You do not have to drive the same way each time, as long as you travel at about the same speed as the lead car.

Each subject drove the experimental route twice to familiarize himself with the road and the test car.

All subjects were given the habitual driving instruction first. The order of the maximum safety and emergency instructions was varied randomly from subject to subject.

Each subject drove twice under each instruction, at each of two speeds, making a total of 12 runs per subject, or four runs per instruction.

The subject drove alone in his car. The lead car driver was accompanied by an experimenter until he had been thoroughly trained. He then drove alone, operating the camera by a remote control cable.

Phase II. Estimation of Following Distance.—Various techniques of estimating distance were evaluated for their utility in aiding the subject to maintain a pre-set following distance.

The subject was introduced to the concept of car length as an interval of 16 ft. He was then positioned in the test car at distances from 1- to 10-car lengths behind another car. Positionings were in whole car lengths and were made both while approching and while withdrawing (backing away) from the lead car. The subject was told the number of car lengths at each position.

TABLE 2

FOLLOWING DISTANCE IN RELATION TO SPEED AND MENTAL SET (INSTRUCTIONS)

Speed (mph)	Following Distance (car lengths)					
	Emergency Set		Habitual Set		Safety Set	
	Mean	S D.	Mean	S.D.	Mean	S D.
30	3.0	1.9	5.8	4.2	6.1	4.7
50	5.6	3.7	11.5	8 7	13.6	10.9

He was next asked to approach the stationary lead car and stop at a distance of 6-car lengths. He was told his actual distance. This procedure was repeated, stopping at 8-car lengths. Training was continued until the subject was able to estimate both distances, twice in succession, with an error of less than ½-car length. He then drove two runs maintaining each of the two following distances, making a total of four runs. No special visual or other experimental cues were used during this part of Phase II.

The subject was then trained in the use of fusion stimuli as an aid to distance judgment. The special stimulus board (described earlier) was attached to the rear bumper of the lead car. From the driver's seat in his car, the subject was shown that each member of the pairs of bars could be differentiated at close range, but as the distance increased, the pairs tended to fuse into a single stripe, in inverse proportion to the width of the space separating the pair. The same phenomenon was demonstrated with the open "C" or Landolt rings.

The subject familiarized himself with both the bars and rings at a distance of 6- and 8-car lengths. He was trained in approaching and stopping at a specified distance behind a stationary lead car until he could fulfill the accuracy requirements previously specified.

The subject was then taught the use of a time judgment method of distance estimation. He was trained to count 10 sec, by saying aloud "one thousand one, two thousand two, three thousand three..." until he achieved an error of less than 1 sec. The subject then made two training runs, accompanied by an experimenter. During these runs the subject attempted to maintain specified separations of 1½ and 2 sec between his and the lead car. These were the time equivalents of 6- and 8-car lengths. Fixed objects, such as expansion joints in the pavement, road signs, or guardrail posts, were used as reference points.

When training in the use of fusion and time judgment techniques was completed, the subject made eight runs, two for each combination of technique and following distance. Instructions for the judgment aid and following distance were given at the beginning of each run. A speed of 40 mph was used throughout Phase II.

Method of Measurement

Frame-by-frame analysis of the films was used to measure the following distances. Thus, the exact separation of the vehicles was measured at intervals of ⅛ sec.

Technical difficulties prevented the use of the target board as a reference in some of the films. However, other fixed reference points on the vehicle proved to be equally useful and the over-all maximum error of measurement was less than 3 percent.

Unfortunately, a certain number of run films were unusable, for a number of technical and operator error reasons. Thus, 25 of 26 subjects produced usable data for Phase I and 18 of 26 subjects for Phase II.

RESULTS

Phase I. Mental Set

Mean following distances and times for all subjects under each instruction and speed are given in Table 2, and the analysis of variance results in Table 3.

The analysis showed that the effects of both instructions and speeds on following distance were significantly greater than the differences between subjects and between measurements. This was true because the error term used for making the F-test contained both subject and measurement effects. The interaction between speed and instruction was also significant. No term involving trials was significant.

When the means of Table 2 were examined for the explanation of these findings, the Duncan range test showed that significant differences occurred between the means for emergency instructions and those for either habitual or safety. There was no significant difference between habitual and safety instructions at 30 mph.

Inasmuch as neither trials nor subjects nor individual measurements significantly affected the results, it is believed that all problems of measurement and procedure were satisfactorily solved.

Phase II. Estimation of Following Distance

Errors of estimation may be positive (underestimation, that is, greater than requested following distance) or negative (overestimation). In a continuous pursuit task such as following, both types of error may occur during the same trial period. In fact, errors in one direction may be the result of overcompensation for errors in the other. Analysis of these errors may be in terms of the direction of error or the absolute amount of error.

Analysis of the direction of error is called vector error and is obtained by algebraically summing all individual errors. Thus, the negative errors compensate for, or cancel out, positive errors, and vice versa. The absolute error, called scalar error, is obtained by adding the absolute values of all the individual errors. The direction, or vector, score gives the direction and magnitude of the subject's average error; the absolute or scalar score gives the over-all magnitude of the error.

Hence, a subject who underestimates by 1-car length 50 percent of the time, and overestimates 1-car length the other 50 percent, would have a direction (vector) error score of 0 and an absolute (scalar) error score of 2.

TABLE 3

LENGTH OF FOLLOWING DISTANCE IN RELATION TO MENTAL SET, SPEED, AND TRIALS—ANALYSIS OF VARIANCE
(N = 25)

Source	df	MS	F
Mental set	2	860.66	20.13[a]
Speed	1	2,089.61	48.87[a]
Trials	1	11.64	0.27
Mental set × speed	2	154.42	3.61[b]
Mental set × trials	2	21.48	0.50
Speed × trials	1	2.25	0.05
Mental set × speed × trials	2	6.11	0.14
Within cells (error)	288	42.76	
Total	299		

[a]Significant beyond the 0.01 level.
[b]Significant at the 0.05 level.

TABLE 4

MEAN VECTOR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE BY JUDGMENT AID AND DISTANCE[1]

Distance (car lengths)	Judgment Aid (car lengths)					
	Habitual		Fusion		Timing	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
6	1.7	2.6	0.3	1.5	-0.2	1.7
8	1.5	2.9	-0.2	3.3	0.2	1.9

[1] Positive means indicate errors of underestimation (distance greater than required); negative means indicate errors of overestimation (distance less than required).

TABLE 5

VECTOR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE IN RELATION TO ESTIMATION AIDS, SPECIFIED DISTANCES, AND TRIALS— ANALYSIS OF VARIANCE
(N = 18)

Source	df	MS	F
Aids	2	55.95	12.16[a]
Distances	1	0.46	0.10
Trials	1	0.70	0.15
Aids × distances	2	2.50	0.54
Aids × trials	2	0.00	0.00
Distances × trials	1	2.83	0.62
Aids × distances × trials	2	1.07	0.23
Within cells (error)	204	4.60	
Total	215		

[a] Significant beyond the 0.001 level.

The mean vector scores for all subjects under each condition of distance and judgment aid are given in Table 4, and the analysis of variance in Table 5. Table 6 gives the scalar scores, with the analysis of variance in Table 7.

From Table 4 it is apparent that without judgment aids subjects tended to underestimate following distance. That is, they thought the distance was shorter than it actually was, and therefore used a longer distance than was required.

Analysis of variance confirmed the significance of the effects of both types of judgment aid: the level was better than 0.001. Examination of the mean differences by t-ratios indicated that there was no significant difference between the effects of visual fusion and timing judgment aids.

Actual car lengths of error were about the same at one distance as at the other, but percent of error (length of error divided by length of required distance) showed a consistent decline for the longer distance, under all three judgment conditions.

The absence of significant effects by trials, or by any of the interactions, when compared to subjects and measurements, indicates that reliability has been achieved in spite of difficulties of measurement, design, and subject selection.

TABLE 6

MEAN SCALAR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE BY JUDGMENT AID AND DISTANCE

Distance (car lengths)	Judgment Aid (car lengths)					
	Habitual		Fusion		Timing	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
6	2.1	13.0	1.2	4.6	1.4	5.3
8	2.2	14.3	1.5	6.8	1.5	6.6

TABLE 7

SCALAR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE IN RELATION TO ESTIMATION AIDS, SPECIFIED DISTANCES, AND TRIALS—ANALYSIS OF VARIANCE (N = 18)

Source	df	MS	F
Aids	2	13.75	5.75[a]
Distances	1	1.34	0.56
Trials	1	5.80	2.43
Aids × distances	2	0.12	0.05
Aids × trials	2	0.74	0.30
Distances × trials	1	2.11	0.88
Aids × distances × trials	2	0.07	0.03
Within cells (error)	204	2.39	
Total	215		

[a]Significant beyond the 0.05 level.

The virtual elimination of vector errors when aids are used indicates that the habitual tendency to follow at a distance greater than requested can be overcome by using such aids. Reduction in the scalar errors indicates that judgment aids also assist the subject in reducing the total amount of error.

ANALYSIS

The absence of significant differences between habitual and safety sets suggests that either these drivers did not interpret the instructions correctly or they believed that they habitually drove as safely as possible. This was checked at the end of testing, by asking the subject whether he felt the distances he maintained under safety instructions were sufficient to preclude collision. Answers were always affirmative. When asked whether he could have driven closer under emergency instruction, the subject often indicated that he could have used a shorter distance but thought his instructions required at least some margin for safety.

These responses seem to indicate the subjects really did not perceive significant differences at 30 mph between the distances they ordinarily preferred and those affording maximum safety. This perception is even more striking when one realizes that some subjects drove at distances less than 3-car lengths at 30 mph, yet insisted that these distances were completely safe. Other subjects dropped back as far as 50- or 60-car lengths, and one drove over 100-car lengths behind, under "safety" instructions.

The data on estimating following distance indicate that it is possible to reduce error substantially by providing simple judgment aids. Even greater improvement may be possible with more refined aids.

Actual amount of error remained approximately the same at 6- and 8-car lengths; that is, percent of error was less at 8-car lengths for each aid used than it was at 6.

The general tendency to underestimate, or err in the direction of greater separation, implies a general resistance to driving at distances as short as 6- or 8-car lengths when speed is 40 mph. Available data on length of following distance support this conclusion.

CONCLUSIONS

Analysis of the data resulted in these conclusions for the subjects used:

1. Following distance is a stable measure of driving performance.
2. Both speed and emergency instructions affected following distance, with the higher speed resulting in longer distances and the emergency mental set resulting in shorter distances.
3. Percent of error was significantly less at the longer of the two requested following distances.
4. Use of the visual and timing aids resulted in significantly lessening the tendency to follow at a greater than requested distance.
5. On the average, drivers drove at about the same following distance under both habitual and maximum safety instructions, at 30 mph.

ACKNOWLEDGMENTS

This research was conducted under contract with the Bureau of Public Roads, Department of Commerce with Richard Michaels serving as contract monitor.

The authors wish to express their gratitude to John E. Robinson, Jr., and Neil J. van Steenberg for their assistance in the design and conduct of this study.

Visual factors were tested with the T/O Vision Tester manufactured by Titmus Optical Co., Inc., Petersburg, Va.; brake reaction time was measured with the Upright Reaction Tester, Model 3594, manufactured by Allgaier Shops, Arlington, Va., and available through the American Automobile Association.

REFERENCES

1. Chandler, R. E., Herman, R., and Montroll, E.W., "Traffic Dynamics: Studies in Car Following." Operations Research, 6:165-184 (1958).
2. Committee on Highway Capacity, Department of Traffic and Operations, Highway Research Board. Highway Capacity Manual. Government Printing Office, Washington, D.C., 3-4:23-65 (1950).
3. Forbes, T.F., et al., "Measurement of Driver Reactions to Tunnel Conditions." HRB Proc., 37:345-357 (1958).
4. Freeborn, K.L.C., and Orchard, D.L., "Report on Methods of Measuring the Headway of Vehicles, Etc." Road Research Lab., Note RN 1116.
5. Goldstein, L.G., and Mosel, N.J., "A Factor Study of Drivers' Attitudes, with Further Study on Driver Aggression." HRB Bull. 172, 9-20 (1958).
6. National Safety Council, "Accident Facts." Chicago (1959).

Some Solutions of Visibility and Legibility Problems in Changeable Speed Command Signs

HERBERT J. BAUER, Senior Research Psychologist, Engineering Mechanics Department, General Motors Research Laboratories, Warren, Mich.

This report details the unusual, as well as the usual, design criteria specified for a discrete-bulb, matrix, speed command sign. Laboratory tests and various results are discussed. The interaction effects found among criteria meeting design specifications are pointed out. The speed command sign in use with the "Traffic Pacer" system in Warren, Mich., is the end product of the research. Specifications, sketches, and photographs, as well as research data, are included.

• SPEED COMMAND SIGNS, whether painted or electric, are certainly no new phenomena on highway systems, nor are the problems of visibility and legibility new problems. However, more advanced highway designs have presented situations wherein the painted, reflectorized, bi-message sign is no longer adequate. The traffic-handling problem of limited access highways and tunnels has suggested that changeable speed commands must be provided for the drivers in the system in order to obtain maximum volume handling on these systems. The personnel at General Motors Research Laboratories found themselves in the "sign business" particularly because of the experimental traffic pacing system which the laboratory has installed on Mound Road in Warren, Mich., (Fig. 1). The nature of this system is such that the drivers on Mound Road have to be presented with frequently changing speed commands. Initially it was not clear just how many different messages would have to be presented to drivers. It was anticipated that speeds such as 40, 35, 25, 20, and 15 mph would have to be made available. The changes must occur instantaneously. It was further ascertained that during certain periods of time the speed command signs must blank out completely; that is, no message was to be presented. During the early stages of the development of this system the then commercially available signs, such as those typically found in sports arenas, were investigated for possible use. It was soon established that they would not meet the criteria that had been set for the speed command signals on the General Motors Traffic Pacer system. Consequently, a new design had to be devised.

The criteria that were established fall roughly into three categories: (a) psychophysical, (b) mechanical, and (c) cost.

The psychophysical criteria fall into three subcategories. First, there is the general psychophysical criteria. These were (a) the sign must be instantaneously changeable to read from blank message through 99, and (b) the sign must present its message with such legibility that there would be a minimum of reading errors.

The second group of psychophysical subcriteria were those relating to the conditions under which the sign would be viewed. It was intended that the sign should be legible from a distance of 500 ft (intentional restriction). The exposure time (that is, viewing time) was to be approximately 1 sec (for test purposes only). The sign was to be legible whether illuminated with high-level lighting directly in front or high-level lighting directly behind. It was further stipulated that the sign must be useful for both day and night use without the necessity of electrical or mechanical changes being introduced from one condition to another.

Weather conditions were also to be considered. Legibility in rain and snow were to be assayed. It was specifically stipulated that as much as $\frac{1}{16}$ in. of solid frost or ice must be tolerable on the face of the sign.

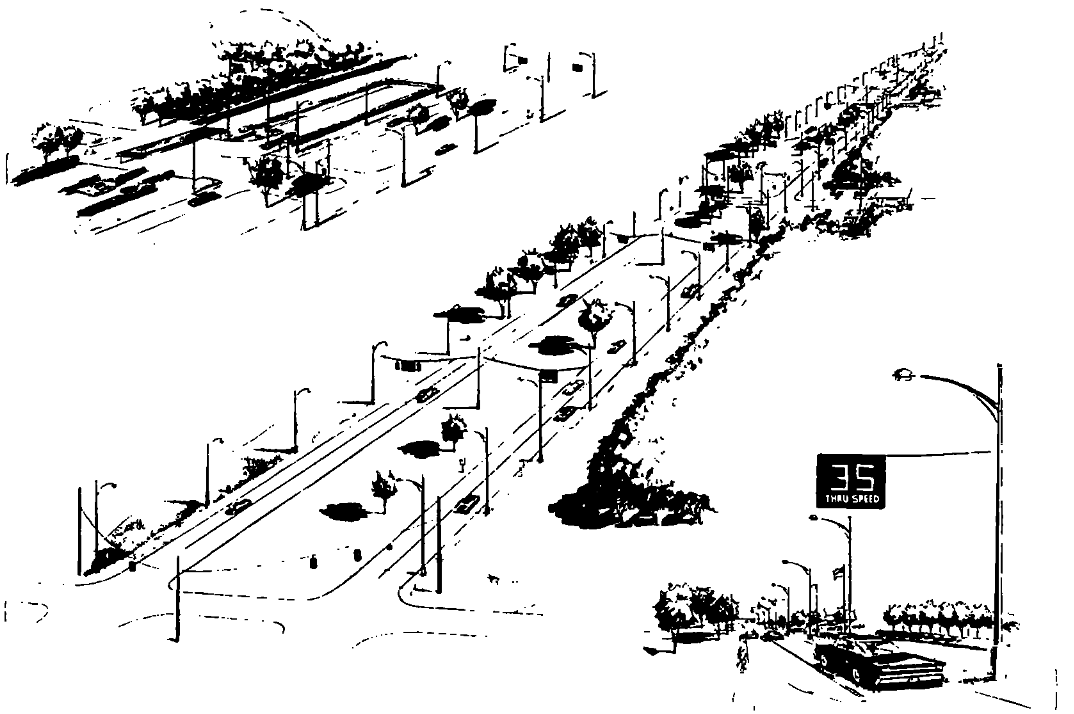

Figure 1. View of GMR Traffic Pacer system, Mound Road, Warren, Mich.

Inasmuch as the sign was to be devised of discrete electric light bulbs, it was also indicated that the design of the configuration of numerals must be such that some bulb failure was permissible.

The third set of psychophysical subcriteria related particularly to the numeral characteristics. They were to be legible almost without error. Furthermore, the numbers themselves had to have a chromatic quality somewhere between yellow and amber. They had also to be linear; that is, not to be composed of discrete points of light, as is the case of the typical matrix-type electric bulb sign, but instead, the numbers were to appear as though they were composed of single broad strokes of light. Finally, the sign had to be such that it could be completely blanked out. During certain periods the speed command sign must show no numerals of any kind. Incident light falling on the sign must be controlled in such a manner that the reflections from the bulbs would not present the driver with an erroneous display.

From the mechanical standpoint the sign was to be somewhere in the order of 4 by 2 ft in over-all size with a thickness to about 12 in. The weight was to be held under 100 lb. The mechanical features of the sign were to be such that a minimum amount of dirt could collect on its face. Adequate ventilation was to be provided. Ease of maintenance and replacement was to be assured for the conditions under which replacement might have to take place could be very adverse. As previously stated, no day-night bulb voltage changes were to be tolerated. The cost criteria were just what one would expect: keep the cost at a minimum, use standard available parts wherever possible.

GMR SIGN

In many respects the Research Laboratories sign is not at all unique. Like many others it is a discrete-bulb, 5 by 7 matrix sign. Used in pairs it is capable of flashing numerals through 99. It is relay operated through a central control system. However,

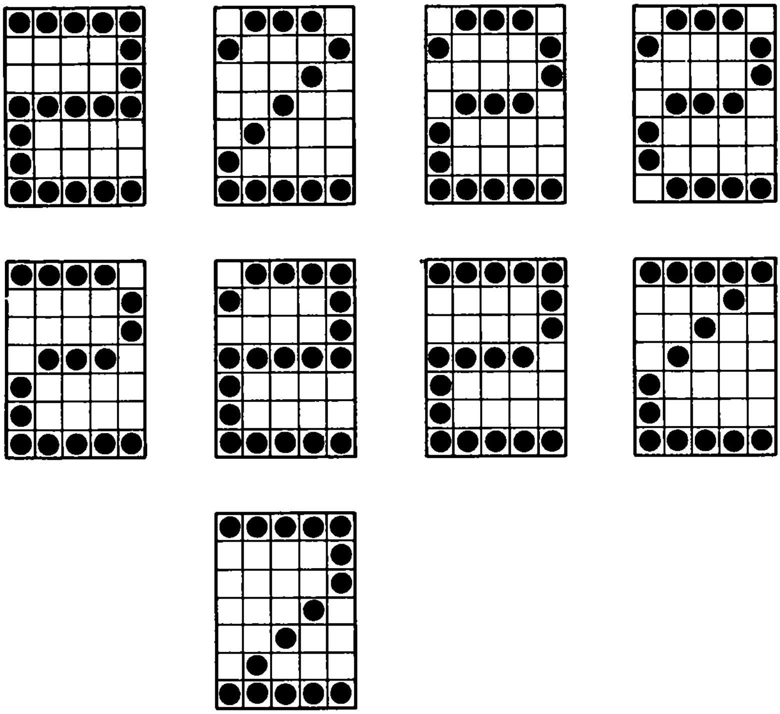

Figure 2. Typical configurations tested for numeral 2.

there are three aspects of this sign that are perhaps unique. The first of these relates to the configuration of numerals employed, the second relates to the linearity of the figures, and the third to its capability of blanking.

Numeral Configuration

Before experimentation a number of commercially available signs were tested. It was found that they would not meet the criteria established for the Traffic Pacer system. Those tested failed on two primary grounds: legibility at the specified distance and lighting condition, and/or too many reading errors when viewed at the criterion distance and exposure time. It was decided that a new set of numerals had to be developed. A large number of configurations were constructed in printed form (Fig. 2). These were tested for legibility and confusion in paper and pencil form. From the results of these early tests a prototype sign consisting simply of a bulb matrix was constructed and the final set of configurations for the numerals 0 through 9 were selected.

The prototype configurations were tested under three different conditions:

1. Bright sunlight, clear sky, with sun incident on the sign face with minimum shadow in the bulb cells.
2. Bright sunlight, clear sky, with sun behind the sign (the sign oriented for maximum brightness behind it).
3. On a dark, moonless night.

The test numerals were presented in the same manner in each test condition. (The tests were conducted for the author by R. L. Bierley of GMR.) One digit was presented at a time to each of the experimental subjects. The sequence of presentations was taken from a table of random numbers. In the final test each of the 20 subjects viewed each numeral five times. Exposure time was 1 sec.

During the course of the testing some configuration modification needs became apparent. Once these were made the previous test data were discarded and the entire

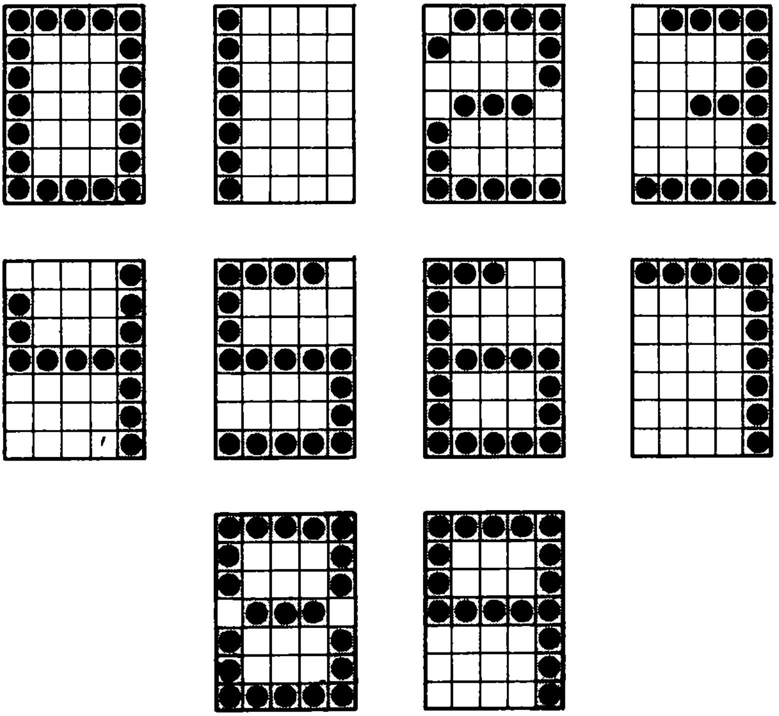

Figure 3. Numeral configuration.

testing program was renewed. No subject served for testing of the revised figures if he had served for any earlier version.

In a total of 1,000 presentations (final test) there were no errors of identification or confusion of the various numerals when presented for 1 sec at a distance of 500 ft under any of the experimental conditions: front lighting, back lighting, or darkness. Furthermore, random bulb failures were introduced and further testing continued. It was found that as many as 5 randomly selected bulbs could be failed in any one numeral before the numerals became illegible or were misread. The numeral configurations shown in Figure 3 are those finally selected. Although not all numbers seem to conform with aesthetic principles or presumed logic, it is known that under careful experimentation conditions they have tested adequately.

Figure Linearity

One of the criteria was that the numerals should not be viewed as the typical discrete points of light, but rather that they should present to the viewer the impression that the numerals are composed of solid bold strokes of light. This condition has been achieved. The GMR sign (Fig. 4) does not have the characteristic cylindrical or conical reflector or surround, but rather the bulbs in the GMR sign are located in a honeycomb-like structure of rectangular cells. The linearity achieved is fundamentally a function of this rectangular as opposed to circular cell structure. The linearity is further enhanced by the use of colored frosted bulbs. The linearity can further be enhanced by the use of lightly frosted glass or plexiglass in front of the cells. However, such an addition is in conflict with some of the other requirements (especially daylight usage) of the sign.

Sign Blanking

The speed control sign for the Traffic Pacer system has one requirement generally not found in typical commercial bulb electric signs—blanking. During certain phases

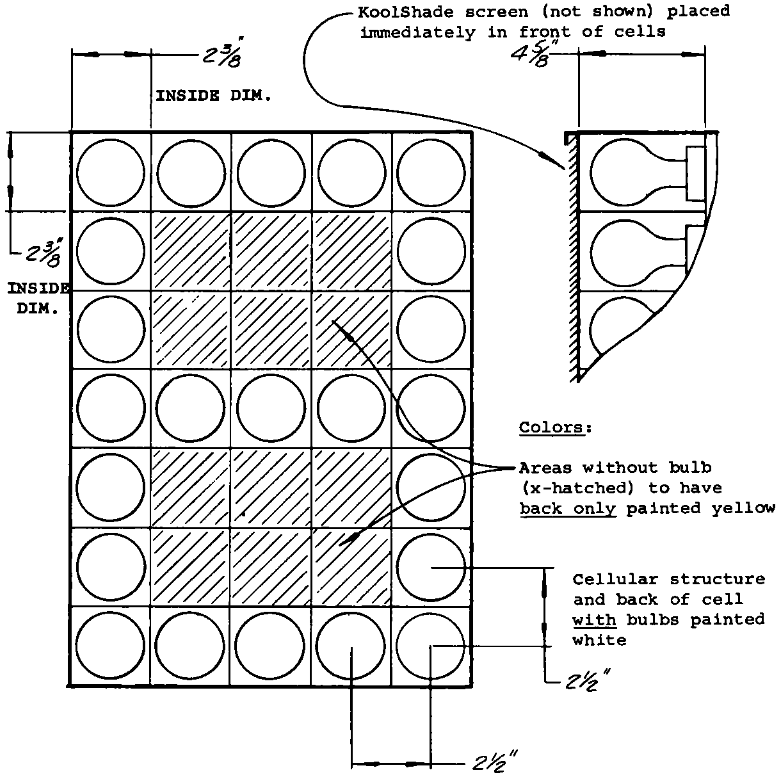

Figure 4. General design of matrix and cells.

of the signaling sequence it is required that no numbers appear on the sign. The difficulty encountered arises out of the fact that incident daylight, and especially direct sunlight, will reflect from the bulbs to a greater or lesser degree depending on the type of bulb and the type of cover (plexiglass, etc.) in front of the cells. Under some conditions the sign appears to be displaying the number 88 (due to bulb configuration) when the current is off but sunlight is incident.

The first attempt to solve the blanking problem was to use shields (sun shades) at the top and side of the sign. This solution was not particularly successful. The size of the shield required for a complete coverage at all sun angles was too great.

The second attempt was a combination of cell color and bulb type. The use of black cell interiors contributed significantly to the reduction of erroneous readout, especially when combined with clear, rather than frosted, bulbs. Clear bulbs did not give the linearity (straight-line letter stroke) desired. However, the numbers were now optically composed of a series of discrete dots of light. The phenomenon was most pronounced under daylight conditions.

The next attempt was to use front covers of various colors of plexiglass. Although dark amber plexiglass covers greatly enhanced blanking, it also presented other severe difficulties: reflection and heat generation. Except under carefully controlled conditions the reflection of incident daylight on the sign was so great that it tended to obliterate the numbers being presented. In an effort to reduce the glare different degrees of sand blasting of the outer surface of plexiglass were tried. This did eliminate glare, but a new problem presented itself. The incident light now reflected and refracted so that the appearance of the sign face was that of a white or grayish surface with more or less chroma depending on the degree of sandblasting and/or the basic hue of the plexiglass. In itself this is not objectionable. However, this condition reduced the contrast ratio between the illuminated cells and the sign face to the point where daylight legibility was not acceptable. Increases in bulb intensity to increase the contrast ratio were unsuccessful. Too much wattage was required resulting in increased heat generation. Further, some "crispness" of the configuration was also lost by this technique.

The use of plexiglass and glass panels of various molded surface textures was not successful because of the consequent reduction of image definition. The numbers appeared blurred, particularly at night. It might also be pointed out that the use of plexiglass or glass front covers is not recommended by people producing signs of this type commercially. It is their contention (though it was not tested here) that these surfaces accumulate too much road dust and as a consequence reduce the intensity of the light output to a point where it becomes a serious problem.

Figure 5. Blanked speed sign.

The use of "dummy bulbs" to present a homogeneous appearance during blanking periods of the display was considered, but rejected on economic grounds. However, it was found that a dual approach could stimulate homogeneity. First of all, the blank center sections of the sign were also filled with a cell-like structure similar to the rest of the sign. Secondly, the back areas of these cells were painted a color similar to that of the unilluminated surface color of the bulbs used in the sign. This solution though the best thus far was not totally adequate.

Completely satisfactory blanking was finally obtained by the use of a screen of Kool-Shade, type RB, placed directly in front of the cellular structure with the louvers slanting downward. This material may be described as a series of horizontal louvers 0.05 in. wide and 0.005 in. thick permanently set at an angle of 17^0 by warp wires spaced on 0.05-in. centers. The spacing of the louvers in type RB is about 17 louvers per in. The denser screen (type LSA) with 23 louvers per in. was also tested but found to be insignificantly different for test purposes. Therefore, because the price differences were considerable the type RB screen was finally selected as fronting for the speed control sign. This last combination was found to be completely satisfactory for blanking purposes even with low angle incident sun. It is true that at very short distances (15 ft) it is possible to discern the bulbs as distinct from the blank area in the sign. However, at such distances even though the sun be directly incident on the sign it is possible to recognize clearly the fact that the sign is not displaying any given numeral (cf., Fig. 5).

Day-Night Legibility

Next are the problems encountered in providing both day and night legibility without voltage changes to the bulbs. It was found that the ideal daylight sign parameters could not be used without some modification for nighttime usage. The brightness necessary for daytime visibility was too great to use at night. A tremendous halo effect (spill light) was encountered. The result was that a sign visible at 1,000 ft in bright daylight was not legible at more than 300 to 400 ft at night.

The most obvious solution to this problem is simple time-controlled voltage reduction. This was tried and found adequate. However, two factors encouraged research for some other solution: cost and reliability. The latter was of particular consequence inasmuch as total reliability is the product of the reliability of the components. The use of reduced output bulbs proved unsatisfactory because of loss of brightness contrast for daylight legibility. Various colors within the cells of the bulbs were used in an attempt to compensate for reduction in light output.

TABLE 1

TRAFFIC PACER SPEED SIGN BULB AND CELL COMBINATION TESTS SUMMARIZED[1]

Cell Color	Nighttime Voltage (v)	Bulb Type: Clear		White Frosted		Yellow Frosted		Clear Yellow	
		Night	Day	Night	Day	Night	Day	Night	Day
Black	110	2	2A	1	1B	3	1C	2	1A
	90								
	80								
White	110	3	2B	1	4A	4	4A	2	2B
	90			2		4			
	80			3		1			
Yellow	110	2	2B	3	3B	2	4C	NT	
	90							NT	
	80							NT	

[1] All bulbs 25 watts rated at 110 to 120 v; daylight ratings based on 110 v. Test distance = 450 ft. All tests performed with KoolShade 17-in. screen in front of cells.

Legibility Rating Scale

Excellent	=	4
Good	=	3
Fair	=	2
Poor	=	1
Unusable	=	0

Bright Sun Blanking Rating Scale

Excellent	=	A
Good	=	B
Fair	=	C
Poor	=	D
Unusable	=	E

The final solution correlated well with the need for chromaticity which was cited as one of the criteria. General Electric Corporation yellow-enameled bulb 25AY served well. The output of this bulb is only 190 lumens compared with the 260 lumens output of the frosted white GE bulb of the same wattage. (It will be recalled that frosted bulbs enhance linearity as opposed to clear bulbs.) The brightness contrast which is lost because of the reduction in lumens output is adequately compensated for in daylight usage by the additional chroma (color contrast) which in itself enhances legibility. Table 1 summarizes ratings for various combinations of cell colors, bulb voltages, and bulb types which were tested. Not all cells in the table are filled. It did not seem worth while trying; for example, the reduced voltages when 100 VAC was already shown inadequate.

ANALYSIS

The solutions to some of the criteria problems tended to be the converse of the requirement of other criteria. Thus, a white-cell sign with white frosted bulbs and a cool shade screen was ideal for daylight legibility. It was still readable for subjects with normal vision at 1,000 ft the bright sun directed at the face of the sign. Yet the very characteristics that made this sign configuration ideal for daytime use made it unsuitable for nighttime because of the tremendous amount of halo (spill light) produced at night. On the other hand, some of the solutions adopted for one specific criteria actually presented quite automatically the solution for some other criteria problems. For example, the need for chromatic (yellow) numerals was solved by the use of an enameled yellow bulb. This, it developed, was precisely the bulb to use for the reduction of the halo at night. Further, the frosted bulb enhanced the linearity desired for the configuration.

At first it seemed that the final design must be a compromise. It is felt that such is not the case. No aspect has been permitted to be degraded for the sake of bringing another up to required standards. The specifications recommended ultimately for the sign meet the criteria established earlier in this paper.

The mechanical criteria cited have also been met in the design. Briefly, the over-all size of the sign is 38 in. long, 23 in. high, and 10 in. deep. The numerals themselves are 18½ in. high by 13 in. wide. The over-all weight of the sign is 79 lb. The use of the cool shade screen as opposed to a plexiglass or glass front has provided for minimum dirt collection probability and has provided maximum ventilation.

The requirement of 1/16 in. frost on the sign has been also tested for and it has been found that the numerals are still perfectly legible even with this amount of ice on their face.

The ease of maintenance and replacement have been provided for by incorporating into the mechanical design typical maintenance characteristics specified by the principles of engineering psychology. The sign is modular in character. It is color-, shape-, and size-coded for ease of installation of replacement parts. (For example, the entire honeycomb structure can be removed by a one-quarter turn of two fastening devices. All bulbs may then be readily changed.) The entire numeral units, of which there are two in each sign, can be removed by loosening four quarter-turn fastening devices. They are coded so that the probability of replacing a left-hand (tens digit) with a right-hand (units digit) assembly is not possible.

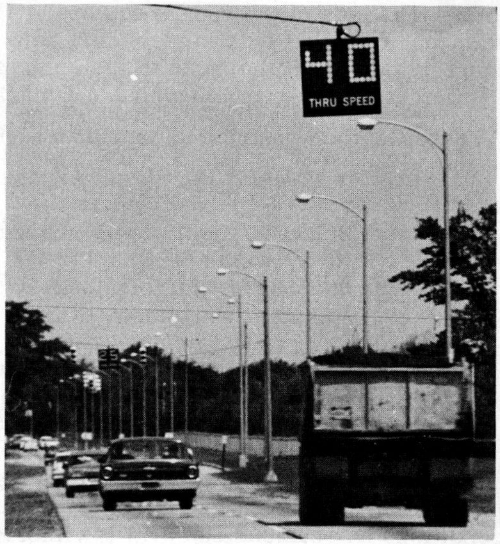

Figure 6. Illuminated speed command sign.

The use of the yellow lamp has precluded the necessity for incorporating a voltage change system.

The cost criteria have been met to satisfaction. However, the bids received from commercial organizations for the construction of this sign varied considerably. The lowest priced bid received was approximately 1/5 of the highest bid received.

<u>Summary of Sign Specifications</u>

1. The sign (Fig. 6) consists of a 5 by 7 bulb matrix composed of rectangular cells 2⅜ by 2⅜ in. square inside dimensions by 4⅝ in. in depth. The cell matrix interiors are painted reflective white with the exception of those cells which do not have bulb sockets, these have a yellow background (sides and edges white) of the same shade of yellow as the bulbs in unilluminated mode. The bulb sockets (ceramic) are on 2½-in. centers (cf., Fig. 4).

2. The numeral configurations shown in Figure 3 have been found most suitable.

3. The recommended bulb is GE 25AY, the yellow enameled 25-watt bulb rated at 130 volts.

4. Bulb-operating operating voltage is 110 volts for greater bulb life. Bulb life vs percent rate of operating voltage is calculated as

$$\frac{L_1}{L_2} = \left(\frac{v_2}{v_1}\right)^{13.5}$$

in which

L_1 = increased expected life;
L_2 = life at rated voltage;
v_1 = reduced voltage; and
v_2 = rated voltage.

The rated life of the specified bulb is 1,000 hr. At 110-volt operating voltage the life is increased to 9,340 hr well within the 3,000-hr replacement schedule practice by the highway department maintaining the signs.

5. The face of the sign is equipped with KoolShade screen, type RB. This screen is mounted so that it is immediately adjacent to the front edge of the matrix cell. Care must be taken that the angle of the louvers are slanted downward. The screen as well as the rest of the sign is painted flat black.

Specifications just listed provide a sign that meets the following requirements:

1. Legible at 500 ft with 1-sec exposure time when viewed under the following conditions:
   (a) Bright sunlight, clear sky with sun incident on sign face with minimum shadow on the bulb cells.
   (b) Bright sunlight, clear sky with sun behind the sign. The sign-oriented maximum brightness behind it.
   (c) Dark rainy, moonless night.
   (d) When sign face is covered with $\frac{1}{17}$ in. of ice.
   (e) When as many as five bulbs have failed.
2. Numerals have definite chromatic (yellow) hue in both daylight and night conditions.
3. Nighttime legibility is as adequate as daytime legibility without the necessity of components designed to reduce bulb voltages with lower ambient lighting.
4. Blanking of sign face when power is removed from the bulbs so that under these conditions no spurious numeral is visible under either day or night viewing.

CONCLUSION

It is not to be assumed that the particular sign described by the previous specifications is the absolute optimum for this particular device or the service for which it is intended. However, the requirements set forth for the speed command signs in the General Motors Research Laboratories Traffic Pacer System on Mound Road in Warren, Mich., have been met satisfactorily by the sign described.

Critical Incidents in Behind-the-Wheel Instruction in Driver Education

JAMES L. MALFETTI, Executive Officer, Safety Education Project, Teachers College, Columbia University, New York, N.Y.
Anderson, William G. Asst. Prof of Education, Teachers College.

• DRIVER EDUCATION, introduced into the high school 16 years ago, is now well established in the curriculum. It is offered at 12,600 of 17,227 public high schools, of which 10,869 give courses including behind-the-wheel instruction (1).

There have been steady improvements in course standards, in materials and techniques, and in teacher preparation and certification. However, most specialists as well as others interested in driver education recognize the need for further improvement and continual appraisal of programs, especially because of the demonstrated utility of driver education in reducing traffic accidents (2).

A significant part of instruction in driver education takes place "behind the wheel." Many factors suggest that this phase is highly important to future driving performance (3, 4). It is also unique: it makes a virtual "classroom on wheels." Part I* of this study is the first empirical attempt to analyze effective behind-the-wheel instruction.

STUDY PLAN

Techniques for identifying teacher effectiveness were reviewed in an effort to discover their applicability to behind-the-wheel instruction. The Critical Incident Technique was chosen because of its success in dealing with similar problems (5, 6, 7, 8); and because it was suited to identifying specific teacher behaviors that could later be used in the development of an evaluative instrument. In this technique, qualified observers describe specific incidents in which an individual performs effectively or ineffectively in terms of the stated aims of the activity. These incidents are then analyzed by abstracting the critically important behaviors in each description; the behaviors are inductively grouped to form categories. The category headings provide an outline of the critical aspects of the activity and ways in which individuals perform effectively and ineffectively in terms of these aspects. In this study, the technique provides a list of effective and ineffective teacher-behaviors in behind-the-wheel instruction.

This study also takes account of the situations in which the teacher-behaviors take place. In a critical incident, important conditions or events that precede or are concurrent with a critical behavior are called situational variables. These are abstracted from critical incidents in the same way critical behaviors are abstracted. The relationship between the variables and critical behaviors is then examined.

This identification of critical aspects of teaching, therefore, describes effective and ineffective teacher-behaviors as well as the conditions under which they took place.

COLLECTION OF DATA

Four groups were selected for the study because their close association with behind-the-wheel instruction put them in a position to judge its effectiveness:

---

*Part I of this two-part study describes effective and ineffective actions of teachers in behind-the-wheel instruction. Based on these actions, Part II will develop an instrument to measure effective teaching. Part II is scheduled for completion in April 1962. In its initial phases the study was financed by the AAA Foundation for Traffic Safety. It is now supported by the National Institutes of Health of the United States Public Health Service (RG-7365).

Group I. High school teachers of driver education.
Group II. College instructors of driver education.
Group III. Supervisors or others responsible for evaluating driver education teachers.
Group IV. High school students taking driver education.

In selecting persons from each group to contribute incidents, an attempt was made to choose a sample representative of driver education in high schools and colleges of the United States as a whole. The number of high school teachers chosen in each State was proportionate to the number of active driver education teachers in the State as compared with those active in the nation. Because of their relatively small numbers, all college teachers of driver education (on lists that could be obtained) were solicited. The total membership of the Supervisors Section of the National Safety Council was invited to contribute. Finally the high school students were selected from each of the six major geographical areas in the country (northeast, north-central, northwest, southeast, south-central, southwest).

All critical incidents were described in writing. Each person was asked to describe at least two incidents, one effective and one ineffective. A full page was made available for recording each incident. Different reporting forms were developed for each group. The following statements introduced the form used with high school teachers (appropriate changes were made for the other groups):

1. Think of the experiences you have had in the behind-the-wheel phase of your teaching in driver education during the past term. Describe an incident in which your behavior was especially effective in helping the student achieve the objectives of the driver education program. (Be sure to include just what you said or did and how it affected the student. Please do not give a general description—try to limit your response to a specific incident.)

2. During the past term there may have been some incidents in the behind-the-wheel phase of the program in which you said or did something which seemed to be detrimental to your student's progress. Describe your behavior in one of these incidents and the effect it had on the student. (Or describe an incident you have observed in which another teacher said or did something which was detrimental to a student's progress.)

Incidents from teachers and supervisors were collected by mail. Students had to be carefully oriented to the purposes of the study before they were able to contribute usable incidents, so a group-interview technique was developed and used. The respondents were assured that the incidents they described would be used only for research purposes, not for personal evaluations.

In keeping with the requirements of the Critical Incident Technique, criteria for accepting incidents were established. Most important among these were the following: (a) the incident must describe an actual happening observed by the reporter; (b) it must

TABLE 1

DISTRIBUTION OF RESPONSES

Group	Mailings	Usable Responses	Effective		Behavior per Incident	Ineffective		Behavior per Incident	Total		Behavior per Incident
			Incidents	Behaviors		Incidents	Behaviors		Incidents	Behaviors	
High school teachers	2,599	516	557	742	1.33	374	388	1.04	931	1,130	1.21
College instructors	282	62	70	105	1.50	59	61	1.03	129	166	1.29
High school students	(68)[1]	775	574	638	1.11	488	488	1.00	1,062	1,126	1.06
Total	2,881	1,353	1,201	1,485	1.24	921	937	1.02	2,122	2,422	1.14

[1] Group interviews.

TABLE 2

SCALE OF AGREEMENT—DISAGREEMENT IN ABSTRACTING CRITICAL BEHAVIORS

Agreement:

A_1 Judge identifies the same behavior identified by the investigator. (He may identify the same words or the same ideas. When both the judge and the investigator underline the behavior, agreement depends on whether they underline essentially the same words. When one or both summarize a behavior, agreement must necessarily depend on the similarity of ideas.)

A_2 Judge identifies as two or more behaviors, material that investigator identifies as one.

A_3 Judge identifies as one behavior, material that the investigator has divided into two or more.

(A_2 and A_3 are considered areas of agreement because in each case essentially the same material was identified. The fact that a judge separates a single behavior into two parts, or vice versa, does not seem to constitute a significant disagreement.)

Agreement-Disagreement:

A-D Judge identifies essentially the same behavior but adds an idea not identified by the investigator, or judge identifies essentially the same behavior but omits an idea identified by the investigator.

(A-D is an area of partial agreement and partial disagreement relating to the identification of a single behavior.)

Disagreement:

D Judge omits the behavior identified by the investigator or identifies another behavior in its place, or judge identifies a behavior not identified by the investigator.

(In accordance with these criteria of disagreement, when a judge and an investigator each identifies one behavior in a given incident and these behaviors are completely different, this constitutes one instance of disagreement.)

Because the category of agreement-disagreement constituted an area of partial agreement, the following formulas were used to determine total agreement and total disagreement:

$$\text{Total agreement} = A_1 + A_2 + A_3 + \frac{A\text{-}D}{2}$$

$$\text{Total disagreement} = D + \frac{A\text{-}D}{2}$$

take place in behind-the-wheel instruction; (c) it must include a clear description of teacher behavior.

In tabulating responses (Table 1), of the 2,599 high school instructors who were mailed critical incident forms, 516 (19.1 percent) contributed usable incidents. Ninety more returned incidents that proved unusable, and 133 explained why they could not comply. A total of 62 college instructors (out of 282 who were sent forms) contributed usable incidents (21.7 percent) and 775 high school students contributed incidents describing the behavior of at least 68 teachers in 68 different schools. (The exact number of teachers is not known because some classes from which student incidents were collected had more than one teacher instructing behind the wheel.) No more than 20 incidents describing the behavior of one teacher (10 effective and 10 ineffective) were accepted.

Only 29 of 626 supervisors returned usable responses. Among the most frequent reasons for supervisors' being unable to comply was "I have not recently had an opportunity to observe behind-the-wheel instruction." Because of the inadequate return, responses from the supervisors' group were not used.

ANALYSIS OF DATA

The first step in analysis was abstracting critical behaviors. Each behavior was identified by underlining the part of the incident that described the action of the teacher judged to be especially effective or ineffective. Some incidents contained more than one critical behavior. Each behavior was coded and recorded. A total of 2,422 critical behaviors was abstracted from the 2.122 incidents used in the study (1.14 critical behaviors per incident) (see Table 1).

A group of 50 incidents (25 effective and 25 ineffective) was selected at random. A member of the study team underlined or summarized the critical teacher-behaviors in each incident. Two judges, competent to use the Critical Incident Technique, were asked to underline or summarize critical behaviors from the same 50 incidents. A scale of agreement-disagreement was developed (see Table 2) and the abstractions of the judges compared with those of the study team. Judge 1 and the study team agreed on 77.8 percent of the critical behaviors abstracted; Judge 2 and the study team agreed on 73.7 percent.

Critical behaviors were inductively grouped into categories. Category headings were devised to describe all behaviors in the category. As the number of behaviors in each category increased, subcategories were developed to account for the different types. Finally, categories and subcategories were grouped under four major areas of behavior.

Originally, critical behaviors contributed by teachers and students were classified separately. On examination, however, the separate classifications proved to be similar, and they were combined although the number of critical behaviors contributed by each group was tabulated separately (see Table 3).

Table 3 lists the 93 critical teacher-behaviors identified by this study. Each behavior is actually a summary statement describing similar behaviors within a subcategory. The behaviors are grouped into 20 categories and the categories are organized under four major areas of behavior. The list describes effective and ineffective behind-the-wheel instruction in terms of the critical behaviors identified in the study.

ANALYSIS OF FINDINGS IN TABLE 3

The number of abstracted critical behaviors contained in areas of behavior, categories and subcategories are given in Table 3. More effective behaviors (1,485) were described than ineffective (937). This may represent a reluctance on the part of students and teachers to report ineffective behaviors. In areas of behavior, 49.80 percent occur in Area I (Control), 30.55 percent in Area III (Analysis), 13.01 percent in Area IV (Special Technique), and 5.12 percent in Area II (Example).

The number of abstracted critical behaviors in each subcategory evidences wide variation. Certain subcategories stand out as frequently mentioned types of critical behavior:

1. Effective analysis of student's bad driving actions (freq. 381) and ineffective analysis of student's bad driving actions (freq. 177) are the two largest. This is due partly to their broadness (each has 6 component behaviors), but it also indicates the importance of the teacher's reaction to student mistakes. Perhaps the student is most educable the moment he makes a mistake.

2. Another frequently mentioned behavior is the teacher's use of the dual-control brake. Effective use to avoid an accident (freq. 111) occurred less frequently than ineffective use in nondangerous situations (freq. 121). This suggests that although the dual-control brake may protect those in the car, its overuse often results in poor instruction.

TABLE 3

EFFECTIVE AND INEFFECTIVE BEHAVIORS OF DRIVER EDUCATION TEACHERS IN BEHIND-THE-WHEEL INSTRUCTION[1,2]

Area of Behavior: I. TEACHER CONTROLS STUDENT DRIVING (T 579 - S 628)

Category: 1. Teacher takes control of vehicle from student driver (T 122 - S 249)

Effective Behaviors	Ineffective Behaviors
a - Applies dual-control brake and/or turns steering wheel to avoid accident (T 59 - S 52)	a - Applies dual-control brake and/or turns steering wheel before any real danger arises and before student has chance to make necessary corrections himself (T 6 - S 115)
b - Applies dual-control brake when necessary to stop vehicle (in its immediate position) to point out student's mistake (T 14 - S 2)	b - Jams on dual-control brake (when student makes mistake) in a way that unreasonably magnifies student's mistake (T 7 - S 9)
c - Takes partial control of vehicle when student needs assistance in performing maneuver or skill (T 21 - S 0)	c - Continually assists student by taking partial control of vehicle without allowing student to perform maneuver or skill by himself (T 15 - S 48)
d - Applies dual-control brake to keep student from committing serious violation (T 0 - S 23)	

Category: 2. Teacher allows student to maintain control of vehicle (does not take control of vehicle) (T 32 - S 10)

Effective Behaviors	Ineffective Behaviors
a - Allows student to make driving error to help him learn through mistake (T 22 - S 7)	a - Allows student to make dangerous mistake (and/or get into accident) (T 6 - S 0)
b - Does not take control of vehicle when time and circumstances permit student to correct his own mistake (T 4 - S 3)	

Category: 3. Teacher directs student control of vehicle before student starts to drive (T 34 - S 36)

Effective Behaviors	Ineffective Behaviors
a - Tells student exactly where to drive vehicle (what route to take) (T 3 - S 3)	a - Gives vague directions in telling student where to drive (T 2 - S 1)

[1] For clarity of organization, the list is divided into "Areas of Behavior" and "Categories." Critical behaviors are listed under categories and are actually summary statements describing groups of similar behaviors. Generally, ineffective behaviors are placed opposite their effective counterparts.

[2] T = number of teacher-described critical behaviors in area of behavior, category, or subcategory. S = number of student-described critical behaviors in area of behavior, category, or subcategory.

Effective Behaviors	Ineffective Behaviors
b - Gives clear and precise description of what actions student should take in performance of driving skill or maneuver (T 10 - S 5)	b - Gives vague and/or incomplete description of what actions student is to take in performance of a skill or maneuver (T 5 - S 8)
	c - Fails to point out what actions need be taken in performance of maneuver or skill (T 8 - S 10)
	d - Incorrectly points out what actions to take in performance of skill or maneuver (T 6 - S 9)

Category: 4. Teacher directs student control of vehicle while student is driving (T 292 - S 310)

a - Gives clear and precise description of what actions to take in performance of maneuver or skill (talks student through maneuver) (T 60 - S 54)	a - Gives vague or confusing description of what actions student should take in performing maneuver or skill (T 7 - S 10)
b - Reminds student what actions need be taken in performance of maneuver or skill (T 11 - S 89)	b - Constantly emphasizes some actions that need be taken and neglects others (T 8 - S 2)
c - Effectively directs student performance of maneuvers or skills (which student already capable of performing) by doing one or more of following (T 30 - S 32)	c - Ineffectively directs student performance of maneuvers or skills (which student is already capable of performing) by doing one or more of the following (T 42 - S 43)
c_1 - Clearly indicates which maneuver or skill student is to perform	c_1 - Gives vague and/or confusing directions as to which maneuver or skill student is to perform
c_2 - Chooses correct moment to tell student when to perform maneuver or skill	c_2 - Tells student to perform maneuver or skill either too early or too late
c_3 - Has student perform in driving situation that helps (or allows) student master specific skills and maneuvers	c_3 - Tells student to perform maneuver or skill not correct in terms of driving situation
d - Tells student what actions to take to cope successfully with impending driving situation (T 33 - S 22)	d - Fails to tell student what actions to take to cope with impending driving situation (T 4 - S 2)
e - Purposely does not direct student driving when student capabilities and driving conditions permit student to direct his own driving (T 10 - S 2)	e - Continuously gives directions when not necessary (T 16 - S 23)
	f - Has student perform in driving situation in which he is not capable of performing (T 16 - S 3)
	g - Tells student to perform maneuver or skill he is not capable of performing (T 17 - S 10)

Effective Behaviors	Ineffective Behaviors
	h - Yells directions at student (T 22 - S 3)
	i - Continuously repeats same (unsuccessful or unnecessary) directions (T 10 - S 2)
	j - Directs student to perform incorrect or unsafe driving maneuvers (T 6 - S 13)

Category 5. Teacher determines when student shall drive (T 74 - S 20)

a - Has student stop car (temporarily) when necessary to have student pay full attention to teacher's explanation (T 11 - S 15)	
b - Has student stop car (temporarily) when necessary to provide student with needed rest (T 7 - S 0)	
c - Allows student to resume driving after harrowing or discouraging experience to help student regain confidence in his driving (T 25 - S 2)	c - Allows student to continue driving when he is not emotionally or physically capable of driving (T 5 - S 1)
d - Discontinues student's driving lesson for remainder of period when student's driving endangers safety of those in driver education car (T 11 - S 2)	d - Punishes student for his mistake by discontinuing student's driving lesson for remainder of period (T 15 - S 0)

Related Sub-Area of Behavior: I_1. TEACHER HELPS STUDENT TO UNDERSTAND REASONS FOR TEACHER'S CONTROL OF STUDENT DRIVING (T 25 - S 3)

Category 6.

a - Explains why he assumed control of vehicle (T 2 - S 1)	a - Fails to explain reasons for using dual-control brake (T 1 - S 0)
b - Explains why he gave student certain directions at particular time (T 10 - S 2)	
c - Explains reasons for discontinuing student's driving lesson (T 3 - S 0)	
d - Explains his function as it relates to control of student driving (T 8 - S 0)	d - Fails to explain his function as person responsible for controlling student driving (T 1 - S 0)

Area of Behavior: II. TEACHER SETS EXAMPLE FOR STUDENTS TO FOLLOW (T 78 - S 46)

1. Teacher sets example as driver (T 46 - S 37)

Effective Behaviors	Ineffective Behaviors
a - Expertly demonstrates driving skills (T 29 - S 32)	a - Fails to demonstrate driving maneuver or skill (T 1 - S 1)
b - Demonstrates lawful and courteous driving behavior (T 3 - S 0)	b - Violates law (or rules of safe driving) in his demonstration (T 13 - S 4)

2. Teacher sets an example for students (during behind-the-wheel instruction) when he is not driving (T 24 - S 8)

a - Behaves in safe, courteous, and calm manner when not driving (T 12 - S 0)	a - Behaves in unsafe, nervous, or impatient manner when not driving (T 12 - S 8)

Related Sub-Area: II_1. TEACHER ANALYZES OWN DRIVING BEHAVIOR (T 8 - S 1)

a - Explains reasons for his own driving actions (T 6 - S 1)	
	b - Refuses to admit his mistakes (T 2 - S 0)

Area of Behavior: III. TEACHER IMPLEMENTS STUDENT'S KNOWLEDGE OF DRIVING TASK THROUGH VERBAL ANALYSIS, EXPLANATION, AND DISCUSSION (T 406 - S 334)

Category 1. Teacher analyzes student's driving actions (T 311 - S 303)

a - Effectively analyzes student's good driving actions by doing one or more of following (T 17 - S 3)	a - Fails to analyze student's good driving actions by doing one or more of following (T 3 - S 1)
a_1 - Identifies student actions that represent good driving	a_1 - Fails to identify student actions that represent good driving
a_2 - Explains why student actions represent good driving	
a_3 - Commends student for his good driving	a_3 - Fails to commend student for his good driving
b - Effectively analyzes student's bad driving actions by doing one or more of following (T 170 - S 211)	b - Ineffectively analyzes student's bad driving actions by doing one or more of following (T 102 - S 75)
b_1 - Identifies student actions that represent bad driving	b_1 - Continually identifies all student actions that represent bad driving
b_2 - Identifies cause of student's bad driving	b_2 - Sarcastically points out student actions that represent bad driving.

Effective Behaviors	Ineffective Behaviors
b_3 - Explains why student actions represent bad driving b_4 - Explains importance of student's bad driving actions b_5 - Explains what student should do to correct or improve his driving	b_3 - Harshly reprimands or critisizes student for his bad driving b_4 - Threatens to fail student or to punish him in some other way for his bad driving b_5 - Laughs at or makes joke of student's bad driving b_6 - Overemphasizes dangers that may result from student's bad driving c - Fails to analyze student's bad driving by doing one or more of following (T 19 - S 13) c_1 - Fails to identify student actions that represent bad driving c_2 - Fails to discover cause of student's bad driving c_3 - Simply berates student without identifying or correcting his bad driving.

Category 2. Teacher allows student to analyze his own driving actions (T 31 - S 16)

a - Provides student driver with opportunity to identify, and make suggestions for correcting his own mistakes (T 21 - S 10) b - Does not identify student's mistake when (a) obvious that the student is aware of the mistake and (b) the student makes so many mistakes it would be confusing and discouraging to identify all of them (T 10 - S 6)	

Category 3. Teacher analyzes actions of other drivers (T 11 - S 5)

a - Analyzes bad driving actions of other drivers by doing one or more of the following (T 11 - S 5): a_1 - Identifies actions of other drivers that represent bad driving a_2 - Explains why actions represent bad driving a_3 - Points out significance of actions for student driver	

Category 4. Teacher assesses student's capabilities and accomplishments as driver (T 39 - S 5)

a - Assures student he is capable of performing maneuver or of becoming good driver (T 17 - S 3)	a - Tells student he will have difficult time learning to drive (T 5 - S 1)

Effective Behaviors	Ineffective Behaviors
	b - Tells student he will never learn to drive or not be good driver (T 14 - S 1)
	c - Compliments student too much for his performance and/or does not give realistic appraisal of student's performance (T 3 - S 0)

Category 5. Teacher orients student to driving task (T 12 - S 5)

a - Points out important elements in driving task and what student must do to cope with them (T 14 - S 5)	

Area of Behavior: IV. TEACHER USES SPECIAL INSTRUCTIONAL TECHNIQUES (T 209 - S 106)

Category 1. Teacher uses special instructional techniques to implement his control of student driving (T 61 - S 29)

a - Has student repeat his directions to make sure student understands and follows them (T 7 - S 24)	a - Uses variety of special techniques for controlling student's driving that prove disadvantage to student (T 5 - S 0)
b - Has student point in direction he is going to turn when student has shown prior inability to distinguish between right and left (T 4 - S 0)	
c - Uses variety of special techniques to enable (slow) student to follow directions more easily (T 12 - S 0)	
d - Uses special methods to bring violations to attention of students who disobey law (T 9 - S 0)	
e - Helps nervous student to relax through patient explanation, direction, conversation, or simply by not saying anything (T 24 - S 5)	

Category 2. Teacher uses special instructional techniques to implement his analysis of student's driving actions, other drivers' actions, and elements in driving situation (T 35 - S 9)

a - Uses skill tests to make student aware of his true driving abilities (T 12 - S 0)	
b - Uses charts and demonstrations to clarify his explanation (T 8 - S 6)	

Effective Behaviors	Ineffective Behaviors
c - Has student get out of car and view driving situation from different or better perspective (T 8 - S 3)	
d - Has driving group discuss and analyze student's driving actions or actions of other drivers (T 7 - S 0)	

Category 3. Teacher uses special instructional techniques to help student master skills (T 55 - S 0)

a - Has student repeat same maneuver or skill one or more times until student corrects his mistake or masters skill (T 21 - S 0)	
b - Has student perform certain (driving) drills to help him master skill or maneuver (T 24 - S 0)	b - Uses drills that inadequately prepare student for real driving situation (T 3 - S 0)
c - Brakes down driving skill into its components to enable student to master it (T 2 - S 0)	
d - Helps student learn to anticipate driving hazards by asking him questions about driving situation he is about to meet (T 6 - S 0)	

Category 4. Teacher uses special instructional techniques in exercising control over composition and behavior of driving group (T 23 - S 3)

a - Changes student from one driving group to another (when first group presents impediment to student's progress) (T 4 - S 0)	a - Places student in driving group that impedes student's driving progress (T 6 - S 0)
b - Conducts driving lesson with one student in car when presence of other students interferes with student driver's progress (T 2 - S 0)	b - Fails to control behavior of driving group (T 3 - S 3)
c - Establishes and explains reasons for class procedures (T 8 - S 0)	

Category 5. Teacher includes special maneuvers, skills, and tasks in behind-the-wheel program (T 20 - S 8)

a - Includes special maneuvers in instruction (such as emergency stop and simulated hazardous conditions) to prepare student better for variety of driving situations he will meet (T 8 - S 0)	a - Unduly restricts variety of maneuvers and skills student performs during course (T 1 - S 8)

Effective Behaviors	Ineffective Behaviors
b - Has student act responsibly and courteously in performing tasks related to driving (T 11 - S 0)	

Category 6. Miscellaneous (T 15 - S 57)

Effective Behaviors	Ineffective Behaviors
	a - Punishes student by actually hitting him (T 2 - S 3)
	b - Distracts student while he is driving by talking about things unrelated to immediate driving task (T 9 - S 39)
	c - Ineffectively organizes driving instruction (i.e., driving time, presentation of new materials, etc.) (T 4 - S 7)
	d - Insists that student use method of performing skill not suited to student (T 0 - S 8)
e - Miscellaneous (T 7 - S 8)	e - Miscellaneous (T 17 - S 4)

3. Precise descriptions of what actions to take in a maneuver or skill (freq. 114) are valuable to effective instruction. They increase the efficiency of instruction by reducing the number of errors, which result from inadequate student understanding of what is expected. In this respect, effective descriptions serve much the same purpose as effective demonstrations.

4. Often effective instruction involves a simple comment that reminds students what actions need to be taken in performing a maneuver (freq. 100). These simple comments (like "check mirror") may need to be repeated frequently to a student—especially when he tends to forget.

Effective subcategories with high frequencies are usually paralleled by, or represent the counterpart of high frequency ineffective subcategories. Thus certain "types" of behaviors (like stepping on the brake) are particularly crucial because they often represent ineffective instruction as well as effective instruction—good and bad teaching involve the same types of behaviors, but they do so at different times, under different circumstances, and in different ways.

Although both students and teachers are considered qualified reporters, the differences and similarities in their descriptions of critical incidents are interesting. Comparisons are based on frequency distributions of abstracted critical behaviors within areas of behavior, categories and subcategories.

Because of the way incidents were selected for the study, student-described and teacher-described behaviors cannot be directly compared on the basis of effective-ineffective distribution. All teacher-described incidents were used. Student-described incidents were randomly selected from each class reporting—up to 10 effective and 10 ineffective incidents per class. Thus, student-described incidents would reflect a more equal effective-ineffective distribution. However, the distribution of teacher-described and student-described behaviors within areas of behavior, categories, and subcategories can be compared by relating the percentage of all teacher-described effective or ineffective behaviors contained in a given category to the percentage of all student-described effective or ineffective behaviors contained in the same category.

Distributions of student-described and teacher-described behaviors within areas of behavior are generally similar, as shown in Table 4. For both groups Area I contains

TABLE 4

FREQUENCY DISTRIBUTION OF TEACHER-DESCRIBED AND STUDENT-DESCRIBED CRITICAL BEHAVIORS WITHIN AREAS OF BEHAVIOR

Area of Behavior	Effective Behavior				Ineffective Behavior				Total Behaviors			
	Teacher-Described		Student-Described		Teacher-Described		Student-Described		Teacher-Described		Student-Described	
	Freq.	Per-cent	Freq	Per-cent	Freq	Per-cent	Freq	Per-cent	Freq	Per-cent	Freq.	Per-cent
I (Control)	354	41.79	316	49.53	225	50.11	312	63.94	579	44.68	628	55.77
II (Example)	50	5.90	33	5.17	28	6.24	13	2.66	78	6.02	46	4.08
III (Analysis)	260	30.70	243	38.09	146	32.52	91	18.65	406	31.33	334	29.67
IV (Special Technique)	176	20.78	38	5.96	33	7.35	68	13.93	209	16.13	106	9.41
Unclassifiable	7	0.83	8	1.25	17	3.79	4	0.82	24	1.85	12	1.07
Total	847	100	638	100	449	100	488	100	1,296	100	1,126	100

most behaviors, Area III is next, and Area IV and Area II follow in that order. Also, this similarity in relative frequencies within areas of behavior is true for effective as well as ineffective behaviors. Apart from this general agreement, however, there are some differences.

Of all effective teacher-described behaviors, 20.78 percent relate to special instructional techniques (Area IV), whereas only 5.96 percent of effective student-described behaviors are in this area. This may reveal the inability of students to recognize special educational techniques. On the other hand, it may also indicate that the relative effectiveness of special techniques is overemphasized by teachers, perhaps at the expense of the more fundamental actions (such as control and analysis) which seem to be critically important more often than teachers realize.

Students, more than teachers, describe ineffective behaviors relating to control (see Table 4). Apparently students are keenly aware of the need to assume responsibility for their own driving and tend to resent interference by teachers. Many teachers should recognize this need and permit students more control over the car when circumstances permit—certainly the objective of driver education must be to allow students gradually to drive on their own. In fairness to teachers, however, it should be admitted that students may overestimate their ability to deal with difficult driving situations. Thus the need for teacher control may be justified more often than students realize.

The distribution of student-described and teacher-described behaviors into subcategories shows a great deal of similarity. Student-described behaviors, however, tend to be more concentrated in certain subcategories, whereas teacher-described behaviors are more evenly distributed (see Table 3). In fact, 29 subcategories have no student-described behaviors, whereas only 2 subcategories contain no teacher-described behaviors. (It should be mentioned, however, that subcategories containing no student-described behaviors usually contain a small number of teacher-described behaviors.) Again, this is probably the result of some limitations in students. It may be difficult for them to recognize and describe in writing the subtleties of teacher-actions.

ANALYSIS OF SITUATIONAL VARIABLES

Situational variables are conditions or events described in a critical incident that precede or are concurrent with a critical behavior. They represent the teaching situation in which a critical behavior takes place. They do not include (a) teacher-behaviors or (b) events or conditions occurring after the critical behavior.

In all areas of education, effective teaching involves flexibility. The good teacher uses methods and techniques appropriate for the teaching situation. Differences in student-capabilities, subject matter, classroom settings, etc., require variation in approaches.

This kind of flexibility is required of the driver education teacher as well, particularly in behind-the-wheel instruction. The same technique or behavior is not always suitable everywhere. It can be good or bad, depending on the situation. For example, the teacher who uses his dual control brake when the student has lost control is performing effectively. But if he uses it when the student has control, he may be performing ineffectively.

The purpose of this analysis of situational variables is to describe critical behaviors more meaningfully by specifying the situations in which they occur.

Abstracting and Classifying Situational Variables

While critical behaviors were being abstracted from incidents, situational variables relating to each behavior were also abstracted and recorded on the same index card.

A total of 130 different types of variables was identified and inductively grouped to form 21 categories. These represented the 21 key situational variables most important to effective teaching. They were grouped into five relatively independent categories so that for a given critical behavior a maximum of one situational variable was abstracted from each of the five categories (see Table 5).

TABLE 5

IMPORTANT SITUATIONAL VARIABLES DESCRIBED IN CRITICAL INCIDENTS

Category	Frequency	Percent
Category I. MANEUVERS, SKILLS, AND OTHER DRIVING ACTIONS BEING PERFORMED AND/OR TAUGHT		
1. Basic skills: starting engine, shifting gears, using clutch, accelerating, decelerating, braking, steering	417	20.0
2. Basic maneuvers (involving a series of skills): driving forward, staying on roadway in proper lane, stopping, backing, turning right and left, turning around, parking, changing lanes, passing	688	33.1
3. Safety precautions used in performance of skills and maneuvers: signaling, checking mirrors, checking for cars and other possible hazards, checking car before driving	150	7.2
4. Driving in accordance with traffic, road, and weather conditions: observing traffic signs and signals, responding to movement of other vehicles, maintaining proper speed for road and traffic conditions, responding to hazards, etc.	789	37.9
5. Courteous driving: actions that show consideration for other drivers and pedestrians	36	1.7
Total	2,080	100
Category II. STUDENT DRIVERS' PERFORMANCE OF SKILLS, MANEUVERS, AND OTHER DRIVING ACTIONS[1]		
1. Student performs (skill, maneuver, etc.) correctly	88	5.3

Category	Fre-quency	Per-cent
2. Student performs (skill, maneuver, etc.) incorrectly, or fails to perform it when necessary	811	49.3
3. Student never performed (skill, maneuver, etc.) before	171	10.4
4. Student previously performed (skill, maneuver, etc.) correctly	6	0.4
5. Student repeatedly performs (skill, maneuver, etc.) incorrectly or repeatedly fails to perform it when necessary	569	34.6
Total	1,645	100
Category III. DRIVING ENVIRONMENT		
1. Practice driving area: not on public streets, enclosed areas, or no traffic area	27	6.3
2. Difficult or hazardous traffic conditions: heavy traffic, pedestrians in roadway, movement of other cars presenting obstacles to movement of driver education car, dangerous actions of other drivers, etc.	322	75.4
3. Difficult or hazardous road and weather conditions: ice, snow, rain, narrow and unpaved roads, etc.	78	18.3
Total	427	100
Category IV. CHARACTERISTICS OF STUDENT DRIVER		
1. Unfavorable temperament for driving or learning to drive: nervous, frightened, excited, emotionally upset, etc.	231	43.8
2. Unfavorable attitude for driving or learning to drive: reckless, overconfident, no confidence, over cautious, know-it-all, reluctant to learn, etc.	99	18.9
3. Not competent for driving or learning to drive: uncoordinated, slow learner, poor vision, etc.	56	10.6
4. Inattentive	32	6.1
5. Inexperienced driver under present conditions	67	12.7
6. Experienced or competent driver	42	8.0
Total	527	100
Category V. POSSIBLE ACCIDENT INVOLVEMENT		
1. Driver education car not in danger of being involved in accident	35	10.2
2. Driver education car about to be involved in accident	308	89.8
Total	343	100
Total	5,022	

[1]Listed under category I.

Table 5 gives the number of times situational variables were mentioned in connection with all critical behaviors. A total of 5,022 situational variables was abstracted in connection with 2,422 critical behaviors. Variables in categories I and II (maneuver being performed, and student-drivers' performance) are mentioned most frequently. Among individual variables, students' incorrect performance (II-2) and driving in accordance with traffic conditions (I-4) have the highest frequencies. Furthermore, variables II-2 and II-5 (both relating to student errors) have a combined frequency of 1,380, which means that one or the other is mentioned in connection with more than one-half of all abstracted critical behaviors. Apparently behind-the-wheel instruction, effective and ineffective, is largely a matter of teacher reactions to student errors of commission or omission.

Relationship Between Situational Variables and Critical Behaviors

The number of times each situational variable was mentioned in connection with a category of critical behavior was tabulated*. An examination of these variables, present when each type of critical behavior took place, provided an excellent indication of the part played by the teaching situation in determining effective or ineffective behavior.

Statistical Analysis.—The χ^2 test was used to discover whether observed distributions of situational variables within categories of critical behavior were significantly different from expected distributions.

The frequency of mention for each specific variable accounted for a proportion of the total frequency of variables within a category of variables (see Table 5). These proportions were used to determine expected frequencies for each variable. For example, the specific variable, "student performs maneuver or skill incorrectly" is mentioned 811 times, and accounts for 49.3 percent of all variables relating to the student-driver's performance (Category II). Thus, when the performance is mentioned, "student performs maneuver or skill incorrectly" might be expected to account for 49.3 percent of the variables.

Expected frequencies for certain situational variables were especially low and did not permit adequate statistical analysis. To overcome this problem, similar variables with low frequencies were combined to form variables called "other"*.

Results.—Application of the χ^2 test to differences between observed and expected frequencies resulted in the identification of 28 groups of situational variables with frequencies significantly different from those expected at the 0.05 level or below*.

A summary follows of the significant relationships between critical behaviors and situational variables:

1. Taking control of the car from the student driver is more likely to be effective when the student (a) is performing complex maneuvers in traffic, (b) makes an error, and (c) comes close to an accident. The same action can be ineffective when the student is performing basic skills under normal driving conditions. Thus a difficult driving situation requires increased teacher control—especially when the student cannot handle it. On the other hand, too much teacher control may occur in the initial stages, when students are learning basic skills under relatively safe conditions.

Allowing the student to maintain control even when he makes a serious error, is frequently effective, provided an accident situation is not created.

2. Teacher demonstrations are effective, particularly when they relate to basic driving skills and when the student has performed incorrectly time after time. Only a small proportion of effective demonstrations relate to the more difficult task of driving in accordance with traffic and road conditions. Perhaps driving safely in traffic is something that is best learned through personal experience.

3. Analysis and explanation of student-driving is more often effective when it relates to (a) complex driving tasks performed in traffic, (b) incorrect student-performance, and (c) dangerous situations. Faulty analysis usually takes place when basic skills and maneuvers are being taught. Choosing proper occasions to explain student mistakes seems to be largely a matter of common sense. Complex or dangerous situations

*Table available from author on request.

represent teachable moments during which students are receptive to explanations. On the other hand, students seem to resent unnecessary explanations relating to elementary mistakes when a simple reminder would suffice.

4. Special techniques are appropriate for instruction in basic skills and maneuvers when students repeatedly make mistakes. Such techniques are particularly valuable when ordinary methods fail.

VALUE OF FINDINGS

The critical behaviors identified in this study should prove valuable to the improvement of driver education in a number of ways:

1. They provide criteria for the development of a measuring instrument to be used in evaluating the effectiveness of driver education teachers. (Part II of this study will develop such an instrument.)
2. College teachers of driver education can use the findings to develop curriculum content in teacher preparation courses.
3. Driver education teachers will find the list of behaviors useful as guides for their own instruction.
4. The findings have many significant implications for other areas of education concerned with the teaching of performance skills.

SUMMARY

Representative samples of high school teachers, college instructors, and high school students of driver education contributed 2,122 critical incidents which described effective and ineffective behaviors of driver education teachers in behind-the-wheel instruction. A total of 2,422 critical teacher behaviors was abstracted from the incidents.

Abstracted behaviors were inductively grouped to form 20 categories and 92 subcategories. Similar categories were grouped under four major Areas of Behavior: Area I —Teacher Controls Student Driving; Area II—Teacher Sets an Example for Students to Follow; Area III—Teacher Implements Student's Knowledge of the Driving Task through Verbal Analysis, Explanation, and Discussion; Area IV—Teacher Uses Special Instructional Techniques. Summary statements, describing behaviors in each subcategory, represent the critically effective and ineffective teacher-behaviors identified in this study.

Frequency distributions of abstracted critical behaviors within areas of behavior, categories, and subcategories, were tabulated. In terms of the system of classification developed from the material, Area I (Control) contained the most critical behaviors (1,207) and stands out as an educational technique uniquely important to effective instruction. In addition, the frequency distributions of teacher-described and student-described behaviors were compared. Generally, students and teachers agreed in their descriptions, but the latter covered a wider range of behaviors.

Situational variables (or important elements in the teaching situation) present when specific critical behaviors took place were also abstracted and categorized. Significant relationships between critical behaviors and situational variables were identified. The results suggest that critical behaviors vary in their effectiveness according to the situation in which they occur.

In Part II of this study, important critical behaviors and situational variables will be used to construct an instrument to measure teacher effectiveness. It will probably consist of a behavioral checklist and will need to be administered by a trained observer. Hopefully it will aid in the supervision and improvement of behind-the-wheel instruction.

REFERENCES

1. "Report on Twelfth Annual National High School Driver Education Award Program." Association of Casualty and Surety Companies, New York (1959).
2. "Driver Education Reduces Accidents and Violations." American Automobile Association, Washington, D.C. (Jan. 1959).
3. "Driver Education: A Syllabus for Secondary Schools." Bureau of Secondary Curriculum Development, State Education Dept., Albany (1957).

4. "Handbook of Human Engineering." Institute for Applied Experimental Psychology, Tufts College, Special Devices Center, Pt. 9, Ch. 4, Sec. 1, Par. 1-2 (1952).
5. Preston, H.O., "The Development of a Procedure for Evaluating Officers in the United States Air Force." American Institute for Research, Pittsburgh (1948).
6. Jensen, A.C., "Determining Critical Requirements for Teachers." Jour. Exp. Educ., 20:79-86 (Sept. 1951)
7. Smit, J.A., "A Study of Critical Requirements for Instructors of General Psychology." Univ. of Pittsburgh Bull. 48, 279-284 (1952).
8. Stewart, L.H., "A Study of Critical Training Requirements for Teaching Success." Jour. Educ. Res., 49:651-652 (May 1956).
9. Flanagan, J.C., "The Critical Incident Technique." Psychol. Bull., 54, 4 (July 1954).
10. Long, B.M., "A Synthesis of Recent Research Studies on Predicting Teacher Efficiency." Catholic Educ. Rev., 4:217-230 (April 1957).
11. "Policies and Practices for Driver Education." National Commission on Safety Education of the National Education Association, Washington, D.C. (1954).

Recognition Time for Symbols in Peripheral Vision

NEIL R. BARTLETT, ALBERT E. BARTZ and JOHN V. WAIT, Department of Psychology and Applied Research Laboratory, University of Arizona

• OF ALL the sensory capabilities exhibited by the driver, the sense of vision is almost wholly responsible for the processing of information in the driving situation. However, little is actually known about the time that this "processing" requires. It was for the purpose of obtaining information on the visual reaction and eye movements, that this research was designed.

The purpose of the project was twofold: (a) to develop a transportable recording system that can be used in moving vehicles to record driver eye movements; and (b) to investigate human response times to signals in peripheral vision.

The importance of developing equipment for obtaining objective data on eye movements and peripheral recognition time can hardly be overemphasized. Such equipment could be used to determine placement of road signs for optimum legibility, to determine speed limits in a high "visual density" zone, and possibly even to develop a method for differentiating the characteristics of good drivers from poor ones. Data from studies on visual recognition time for peripheral signals would certainly be important in determining relationships between speed and driver safety.

The first part of the project consisted of the design and development of an amplifying and recording system which may be used in moving vehicles to record driver eye movements with a minimum of interference to driver activity. The system may be used in any conventional six-passenger automobile without modification of the vehicle. The system was designed so that it could be operated by self-contained batteries, inasmuch as the line voltage of standard automobile electrical systems varies considerably. Another important feature for such a system is compactness and portability. Figure 1 shows the complete system. On the left are the self-contained batteries and the inverter for the recorder. In the center are the preamplifier and amplifier, and on the right is the recorder.

Figure 2 shows the system in actual operation. The driver is not restricted, and the equipment is compact enough to allow one person in the rear seat to monitor the equipment.

The system appears suitable for making eye-movement recordings as larger, less easily transported bioelectric recording equipment. No observable loss in performance accrues from operating the recorder from the storage-battery power pack. The amplifying equipment exhibits stable performance and is reasonably immune to the effects of temperature changes and battery aging.

The most critical factor associated with making good eye-movement recordings is electrode preparation. Electro-depositing equipment was constructed for making chlorided silver electrodes. Some success was achieved in reducing drift by this method. However, more refined equipment should be constructed and a better technique evolved. Further work involving the use of the recording system in actual field experiments should be preceded by a period wherein the investigators evolve and practice electrode preparation procedure to achieve predictable, low drift. Otherwise, the system is suitable as a research tool for making eye-movement recordings both in the laboratory and in moving vehicles.

The second part of this project involved the investigation and determination of response times to signals in peripheral vision. The original purpose for this phase of the project was to check out the recording equipment described earlier, but as the research progressed it was felt that some of the characteristics of eye movements and the process

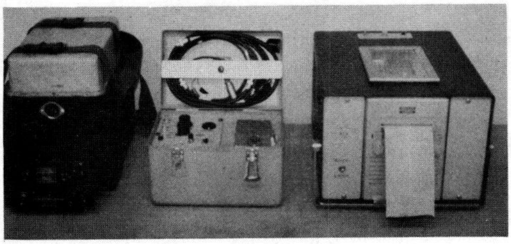

Figure 1. Display of portable equipment for the recording of eye-movement latencies. Left, battery pack and inverter; center, preamplifier and amplifier; right, pen recorder.

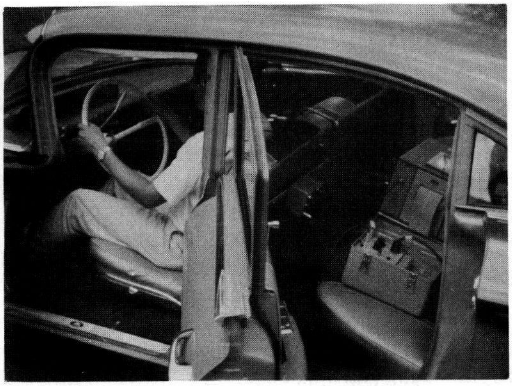

Figure 2. Portable recording equipment installed in an automobile.

of seeing should be systematically investigated. The recording equipment proved to be an invaluable tool in this investigation.

Many studies concerning the various characteristics of eye movements have been carried out since the end of the Nineteenth Century. One of these characteristics, the "speed of seeing," has been particularly important in applications in industry, the armed services, driver safety, and other related areas. It was believed that much previous research was not particularly applicable to field situations, because the type of visual reaction required of the subject did not resemble the actual field situation in terms of complexity and extent of eye movement.

Various components of the visual response were systematically investigated by Dodge and Diefendorf (1). Using photographic recording techniques, they found that the average latency was about 200 millisec. Latency is defined as the time interval between the appearance of a peripheral signal and when the eyes begin to move. They also found that the eye movement itself took from 29 millisec for a 5^0 movement to 100 millisec for a 40^0 movement. Essentially the same results were obtained by Miles (2) and Hackman (3).

These time intervals do not reflect the time involved in the process of "seeing" an object in the periphery. After the eye has fixated on the peripheral stimulus, the observer still must process the new information and make some response.

More recently other investigators have been concerned with the total response time when there is more than a simple movement involved. Hyman (4) found that the total response time increased when the task required the subject to identify the specific location of the stimulus. Words were assigned to various lights and the response time was measured by a voice key set off when the subject pronounced the correct word for the stimulus location. This increase in response time occurred even though the subject was not specifically instructed to move his eyes because Hyman's stimulus lights were so close together.

This type of response time is more closely related to the problem of seeing, inasmuch as the total visual reaction must include an identification of what is seen. As was expected, Hyman found this identification type of response time to be longer—the lengthening being a function of the statistical probability that a stimulus would appear in the specific location identified. Hyman's vocal response times varied from 300 to 750 millisec. However, this complex response still does not represent accurately the process of "seeing" an object in the periphery. To see an object in the periphery the individual must not only identify the location and swing his eyes it, but also interpret the stimulus.

This part of the project was designed for two purposes. Experiment I involved the investigation and determination of response times associated with the interpretation of peripheral stimuli. As a framework for the analysis the following hypotheses were investigated: (a) response times will be longer than the simple movement responses reported by Dodge, Miles, and Hackman; (b) response times will increase as a function of angular displacement from the line of direct vision; and (c) response times will increase as a function of the number of stimuli to which the subject must pay attention.

Experiment II was designed to isolate and measure the various components of the total response time. By using the electrical method for recording eye movements, it was possible to isolate the latency, the travel time of the eye, and the response time for interpreting the stimulus.

The subjects for both experiments were volunteer undergraduates, and were free from pertinent visual defects as measured by an orthorater. All were highly trained prior to the experimental sessions.

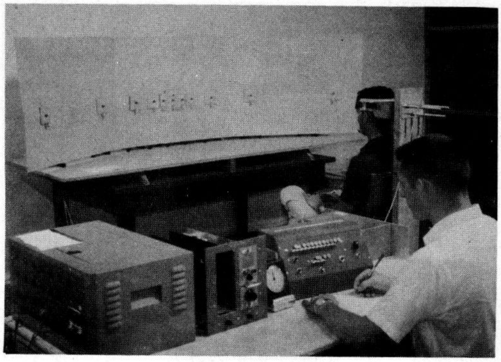

Figure 3. Laboratory layout of apparatus used in standardizing test procedures.

The apparatus for Experiment I consisted of the peripheral stimuli, tracking task, electronic voice key, timer, and appropriate experimenter's controls. The peripheral stimuli were eleven Nixie Numerical Indicator tubes, placed 6 ft on the horizontal plane from the subject at 40^{0}, 20^{0}, 10^{0}, 5^{0}, and 2.5^{0} right and left. There was also one tube at center (0^{0}). The subject, with head held rigid by means of a headrest, performed continuous monitoring on the tracking task at the center of the array of lights. At random intervals one of the peripheral signals came on and the subject moved his eyes to the stimulus and verbalized the numeral presented into a microphone that stopped the timer.

The experimental trials were run for twelve days and were initiated on the day following the training sessions. To test the hypothesis that reaction time increases as a function of the number of possible stimuli, it was necessary to divide Experiment I in two parts—Sequence A and Sequence B. The stimuli in Sequence A consisted of four indicator lights at the 20^{0} and 10^{0} right and left positions. Each session consisted of 144 trials and was presented on days 1, 2, 11, and 12.

The stimuli in Sequence B consisted of the indicator lights in all eleven positions. Each session included 144 trials and was presented on days 3 through 10. The data for both sequences were analyzed by means of a four-factor analysis of variance.

In Experiment II the same apparatus was used for presenting the stimuli. To record the eye movements necessary for measuring the components of the total response, electrodes were placed behind the external canthi of the subject's eyes. The output from the electrodes was fed to the preamplifier and this terminated at an oscilloscope. The upper trace of this dual-channel oscilloscope was a record of the subject's eye movements. For the lower trace the input was from the first stage of amplification of the electronic voice key. The sweep was triggered when an indicator light came on. A Dumont oscilloscope camera was used to photograph the tracings. In Experiment II each subject made a total of 32 recorded responses each day for four days. Figure 3 shows the layout of the apparatus with the subject in position. Figure 4 shows a close-up of one of the stimuli and the tracking task. Figure

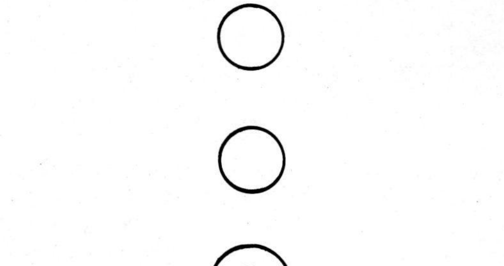

Figure 4. Schematic diagram of one stimulus used in tracking task in laboratory studies.

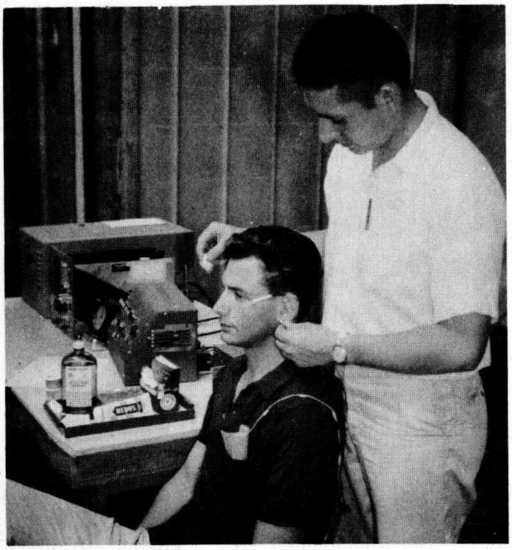

Figure 5. Electrodes being fixed on subject prior to laboratory experimental session.

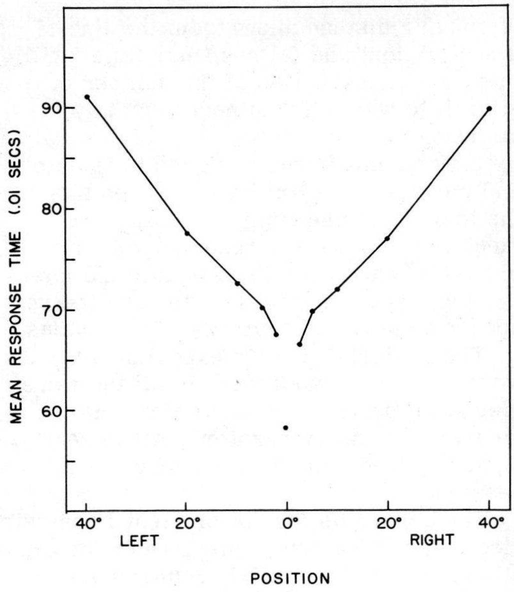

Figure 6. Relationship between lateral location of signal and response time as developed from experimental laboratory sessions.

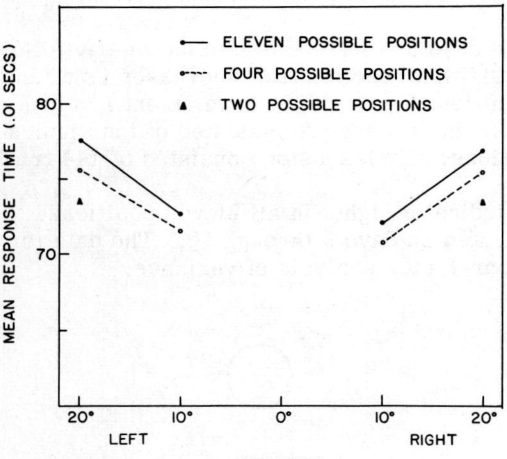

Figure 7. Mean response time as a function of number of possible stimuli.

5 shows the electrodes being fixed on the subject prior to an experimental session.

Results of Experiment I showed that response time increased as the angle from the centerline of direct vision increased. Figure 6 shows the relationship of response time to peripheral angle. There was no significant difference between mean response times to the right and left sides.

It was also found that response time increased as the number of possible signals increased. Figure 7 shows response time as a function of number of possible stimuli. Response time was slowest when the subject had to respond to one of eleven signals, as against one of four, or one of two (training trials).

The results of Experiment II showed that the time required for each of the three components of the response increased as the angle away from direct line of vision increased. Figure 8 shows the portion of the total response made up of each component. It was expected that the latency (the time before the eyes began moving) and the actual eye movement increase as a function of angle. However, the vocalization component (the time required for the subject to make his vocal response after his eyes had reached the signal) also increased with angle. Even though the subject's eyes were at the stimulus, it took longer for him to "recognize" the numeral presented and verbalize the response when the stimulus was at a greater angle in the periphery. Figure 9 shows this vocalization time as a function of angle. The bars represent the mean plus and minus one standard error. It was believed that this was due to changes in either accommodation or the hunting of the eye for an exact fixation.

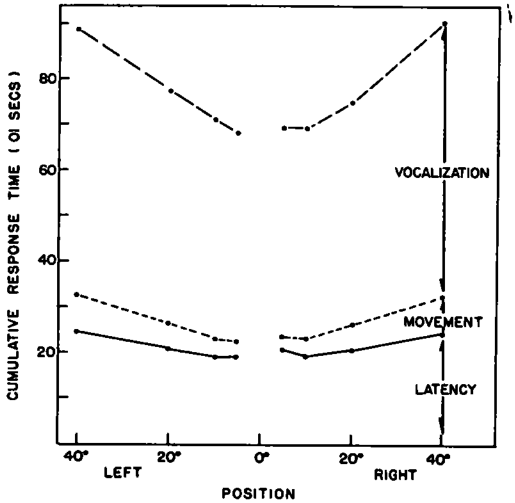

Figure 8. Eye-movement latency and movement, and vocalization as portions of the total response time.

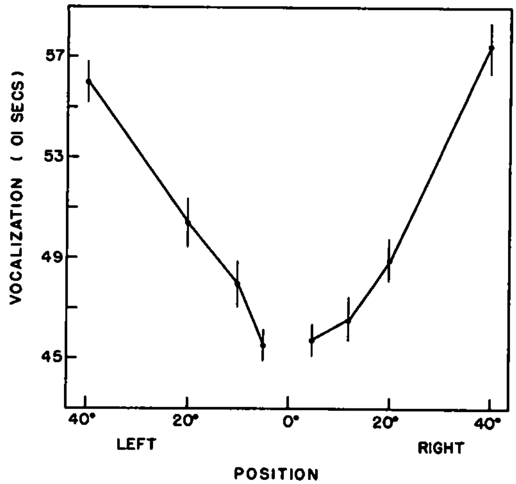

Figure 9. Relationship between vocalization time and lateral position of signal.

It was concluded that the results of the present research indicated that response times are unusually long in a complex visual situation. Further research is contemplated that would yield a mathematical relationship between response time and number of possible stimuli, and results that would explain the vocalization pheonmenon and its relation to angle away from direct line of vision.

ACKNOWLEDGMENTS

The research was sponsored by the Arizona Highway Department and the United States Bureau of Public Roads, through the Arizona Transportation and Traffic Institute, using Highway Planning Survey funds.

This paper is based on research in the development of portable recording equipment for the measurement of eye movement latency for the Arizona Transportation and Traffic Institute, The University of Arizona.

REFERENCES

1. Diefendorf, A.R., and Dodge, R., "An Experimental Study of the Reactions of the Insane from Photographic Records." Brain, 31:451-489 (1908). Cited by Woodworth, R.S., and Schlosberg, H., "Experimental Psychology." Holt, p. 502 (1954).
2. Miles, W.R., "The Reaction Time of the Eye." Psychol. Monogr., 47:268-293 (1936).
3. Hackman, R.B., "An Experimental Study of Variability in Ocular Latency." J. Exp. Psychol., 27:546-558 (1940).
4. Hyman, R., "Stimulus Information as a Determinant of Reaction Time." J. Exp. Psychol., 45:188-196 (1953).

Development of a Vehicle Simulator for Evaluating Driver Performance

RICHARD G. DOMEY and DONALD PATERSON, Harvard School of Public Health, Division of Environmental Hygiene and Safety, Boston, Mass.

• THE MOST desirable approach for assessing the performance of special subgroups of the driving population is to measure behavior while operating within a controlled road-vehicle system. However, the expense, time consumption, complexity, and inherent risks involved suggest more conservative procedures before the highway system is utilized. A practical approach to the study of the problem is to obtain fundamental data in the laboratory with such instruments as universal mock-up devices or simulators. This paper is a summary description of the mechanical, electro-mechanical, tracking and data-computation features of such a simulator developed at the Harvard School of Public Health.

The fundamental design criteria for the simulator are (a) dimensional duplication of vehicle cab interiors, and (b) adequate adjustability range to insure operator comfort. The driver testing procedure must provide experimental task requirements that emphasize biomechanical activity. A study of commercial vehicle cab interiors produced by five major manufacturers indicated insignificant dimensional changes between 1956 and 1960 models. Data previously accumulated by Harvard School of Public Health were therefore considered a valid basis for simulator design (1, 2).

A survey of the human engineering man-machine control system literature led to the adoption of a central, continuous tracking task requiring steering wheel manipulation. A series of pilot studies were conducted at Massachusetts Institute of Technology with Sheridan's (3) apparatus in order to gain familiarization with tracking techniques and methodology. In addition, the studies developed the necessary data for the specification of the equipment components of the proposed simulator.

MECHANICAL FEATURES

The four components (seat, dash panel, pedals, and steering mechanism) of the mock-up were designed and fabricated independently. Each separate component required three physical properties: (a) functional duplication of the truck cab counterpart, (b) remote and/or direct adjustability of the displacements and forces required for activation of control devices, and (c) translational and appropriate angular adjustability. The housing framework was designed contingent on the requirements of each component. Thus, the support structure is spatially compatible with the proper constraint of movable components.

A reference dimension that properly orients each component was established. All ranges of adjustability are measured with respect to the reference values. The referents are equivalent to the optimal dimensions recommended in the data accumulated by Harvard School of Public Health in Table 1. The mock-up interior can, therefore, be arranged to meet the dimensional requirements of a large range of body configurations and can functionally simulate the interior of commercial vehicles.

The degrees of dimensional adjustability of each component, relative to the steering wheel, are given in Table 1.

Seat Mechanism

The seat is a 6-way power unit which was donated for the project by Chrysler Corporation (Figs. 1 through 7). The operator has control of seat position within ranges of 5 in. longitudinally, 2 in. vertically, and 15^0 rotation about a transverse axis.

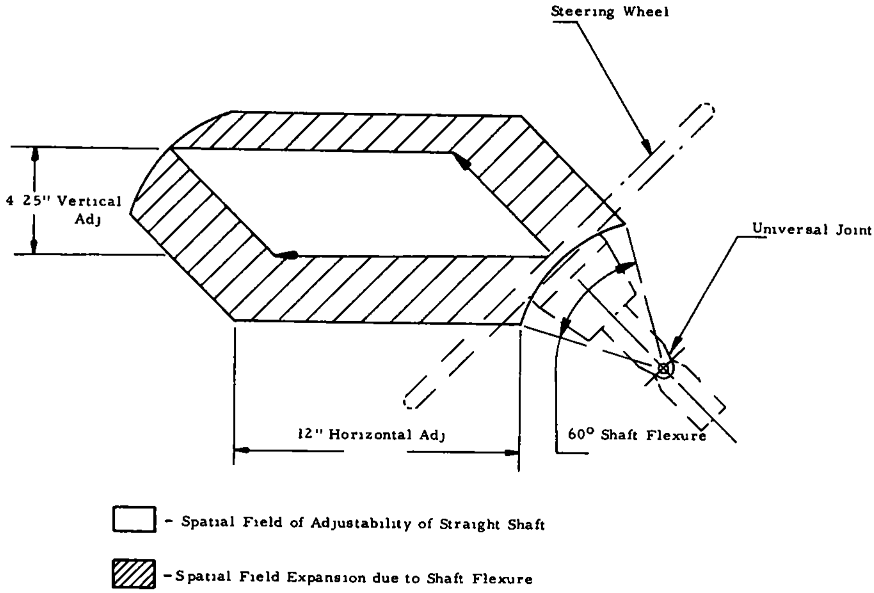

Figure 1. Steering wheel adjustability relative to lowest forward position.

This electrically-powered unit is mounted on a platform that can be moved longitudinally and vertically through ranges of 9 in. and 6 in., respectively. The platform is elevated by a hand-operated pump hydraulically coupled to a power cylinder. The rate of descent of the platform is controlled by throttling the high pressure fluid through a control valve. Longitudinal movement is provided manually through a rack and pinion transmission. The seat platform rests on ball bearing tracks and is driven fore or aft by cranking the pinion anchored to the simulator frame. This arrangement provides for coarse adjustments remotely controlled by the experimenter. Figure 3 shows the seat platform elevated exposing the fine adjustment mechanism of the seat assembly.

Instrument Panel

The variation existing in the instrument panels of commercial vehicles is extensive. Configuration, size, angle, dial clusters, and switching devices vary among manufacturers. The functional differences among manufacturers to be accounted for in the simulator are the relative positions of instrument panel components, accessibility of controls, and the biomechanical mode of manipulation.

Trucks of similar classification that are produced by different manufacturers utilize unlike instrument panel elements for regulating the same control functions. A stockpile of dials, switches, and gauges were accumulated. Interchangeable instrument panels are fabricated to duplicate as many commercial vehicle panels as necessary. Figure 2 shows one instrument panel layout as it appears in the completed simulator.

The frame supporting the instrument panel has two degrees of freedom: (a) rotation about a transverse axis through 40° from vertical, and (b) 12 in. longitudinal translation. These motions are toward or away from the operator.

Floor-Mounted Hand Controls

The lack of standardization of hand brake and shift lever design and location among vehicle manufacturers is compensated for in the simulator.

Shift Mechanism.—The shift mechanism provides for interchangeability of shift levers and variation in operating position. A conventional H-pattern defines the geometric path traversed by the lever knob during a shift sequence. The task required of the subject is to manipulate the lever in a prescribed order to the terminal points of

Figure 2. Frontal view of simulator interior.

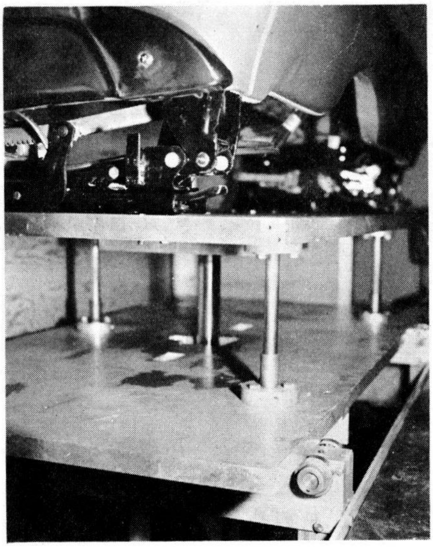

Figure 3. Lateral view of seat mechanism.

the shifting pattern. A wide range of force factors are provided to tax the motor capacity of the operator.

The difficulty in manipulating this device is considered a function of the dimensional limits of lever displacement and the mechanical impedance of the lever but is not necessarily a function of the number of shift poistions. Therefore, the four-position H-pattern was adopted for simplicity. Further, the task required may be any number of movements through any of the possibilities offered by the H-pattern. A control for low and high range may be inserted when required on either lever or push-button form.

Hand Brake.—A generalized mounting bracket designed to accommodate the brake types may be positioned for operation at several alternative locations. Hand brakes have been classified according to four basic types of release mechanisms: (a) rabbit ear grip, (b) pistol grip, (c) button release, and (d) toggle. Specimens of each type

TABLE 1

SPATIAL DIMENSIONS OF CAB SIMULATOR

Variable	Range in Simulator[a]	1956 Commercial Vehicle Variations	Recommendations (1)	Range Civilian Driver Body-Sizing Data
Instrument panel angle (°)	90 - 150	90 - 130	None	None
Seat depth (in.)	18[b] Min.	15.5 - 21.75	18 - 20	—[c]
Seat back height (in.)	22[b] Min.	17.5 - 21.0	18 - 20	20.8 - 26.4 Trunk Ht.
Fore and aft seat adjustment (in.)	14	0.00 - 6.00	6.00	21.3 - 27.6 Knee Ht. 19.3 - 26.0 Butt-Knee Lgth.
Vertical seat adjustment (in.)	10	0.00 - 3.36	4.00	26.4 - 32.9 Norm. Sitting Eye Ht. Abdom.
Seat back to lower edge of s/w horiz. distance (in.)	14 - 28	9.26 - 16.25	12 - 13	6.68 - 13.76 Depth
Vertical distance floor to lower edge of s/w (in.)	20 - 38	20.5 - 27.00	24.5 Min.	19.3 - 26.0 Knee Ht.
Height of seat above floor (in.)	12 - 30	13.5 - 17.75	15 Max.	—[d]
Steering wheel angle (°)	15 - 75	20.5 - 55.0	42.5 - 48.2	45.5[e]
Lower edge of s/w to brake pedal (in.)	18 - 35	19.25 - 30.5	26 Min.	19.3 - 26.3 Knee Ht.
Lower edge of s/w to clutch pedal (in.)	18 - 35	17.0 - 27.6	26 Min.	19.3 - 26.0 Knee Ht.

[a]Dimensions of simulator relative to steering wheel fixed in lowest-forward position (see Fig. 1—s/w range).
[b]Seat depth and seat back height may be altered with cushions.
[c]Buttock-calf distances not taken on commercial driver series by McFarland et al. (1). Comparisons with group of males measured by Hooten in "A Survey of Seating" show this dimension will approximate 17.5 in. for the 5th percentile driver.
[d]Not taken on commercial driver series by McFarland et al. (1). Comparisons with other groups indicate it to be slightly over 17.50 in. (including shoes), suggesting a seat height of 16.50 in.
[e]Kephart and Dunlap (2).

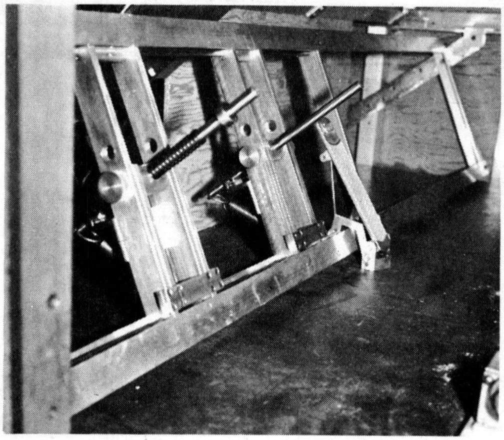

Figure 4. Lateral view of foot pedal arrangement.

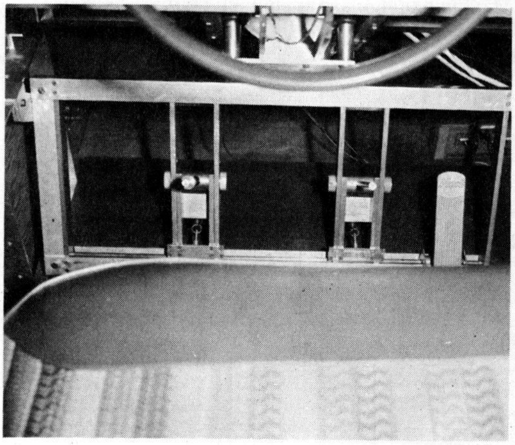

Figure 5. Frontal view of foot pedal arrangement.

have been accumulated. The force required for engaging and releasing levers can be altered by interchanging extension springs of varied force deflection ratios.

Foot-Operated Controls

The foot-operated controls in the simulator are (a) brake, (b) clutch, and (c) accelerator. The clutch and brake elements are similar to one another in construction. Each unit consists of a pedal, shaft, and gimbaled bearing, supported by a carriage. The carriage is mounted in a frame allowing lateral displacement. The frame extends across the cab and forms an integral part of the toe pan at floor level. Various angular and longitudinal positions of the frame are made possible by locking clamps. This type arrangement permits three degrees of freedom for the brake and clutch pedals independent

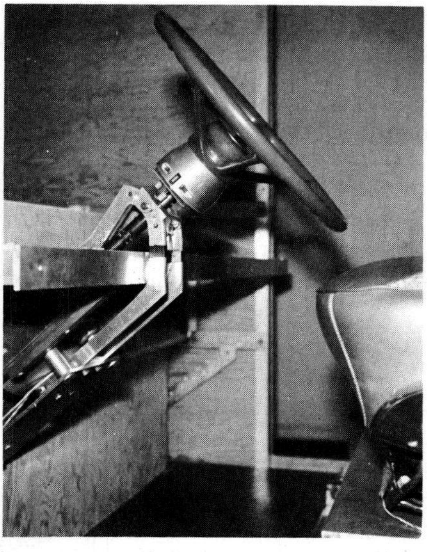

Figure 6. Lateral view of steering wheel mechanism.

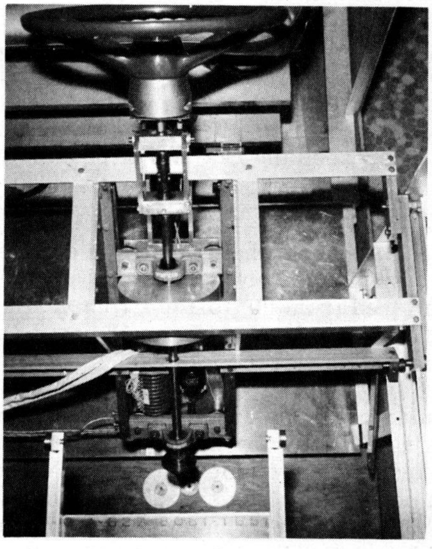

Figure 7. Frontal view of steering wheel mechanism.

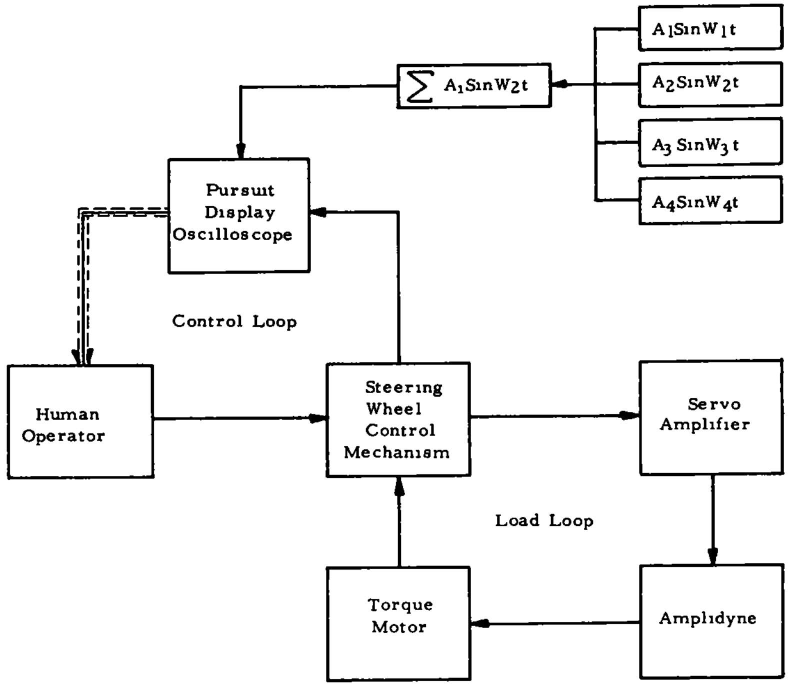

Figure 8. Schematic diagram of tracking apparatus.

of the frame movements. The entire assembly may move in two degrees of freedom.

A perforated aluminum plate fastened to the face of the frame serves two purposes: (a) it provides a backstop for pedal depression and (b) it acts as a toe pan which defines the forward limit of the below instrument panel cab space. Figures 4 and 5 show the assembly with the pedals and toe pan plate removed, to allow better viewing of the assembly.

The clutch, brake, and accelerator pedals are loaded with interchangeable springs that can provide a wide range of force factors. During depression of the brake and clutch the operator experiences two distinct phases. The initial movement of the pedal is opposed by light spring force which is followed by relatively heavy resistance for the remainder of the stroke. This is accomplished by arranging dual springs such that both are compressed only after a predetermined increment of pedal motion. This feature increases the realism of pedal action.

Steering Mechanism

The steering wheel has three degrees of freedom. The shaft may telescope 6 in., the entire assembly moves fore and aft over a 12-in. range, and the wheel angle may be altered from 90^0 to 150^0 from vertical.

The steering wheel is an 18-in. diameter standard International Harvester model. To make the wheel angle variable a universal joint was inserted into the shaft 8 in. from the steering wheel. This allows the steering wheel to be locked in any of seven angular positions ranging between 90^0 and 150^0. The mechanical arrangement for locking the steering wheel in these positions is shown in Figure 6.

A truss-like frame supports the steering assembly at an angle of 45^0. This inclination of the steering assembly approximates the optimum value recommended by Kephart and Dunlap. The frame and steering assembly are supported within the simulator by ball bearing rollers running on tracks placed on the simulator super-structure. This allows the entire steering assembly to be moved fore and aft through a range of 12 in. Figures 6 and 7 show lateral and plane views of the steering apparatus.

The steering shaft is supported by two self-aligning pillow blocks mounted 14 in. apart. The pillow blocks are attached to a framework, which is supported on axial thrust bearings running in lateral tracks. By means of a rack and pinion arrangement the steering unit can be moved 6 in. in a direction parallel to the steering shaft. This action effectively telescopes or extends the steering wheel.

The degrees of adjustment (the 6-in. telescopic action of the steering shaft relative to the frame, the 12-in. fore and aft translation, and the 60° flexure of the shaft) are sufficient to duplicate the steering wheel orientation of existing commercial vehicles.

Force factors are simulated by a torque motor coupled to the steering shaft. This allows simulation of forces encountered in actual driving situations. The system that regulates the steering dynamics consists of several electromechanical transducers housed in the steering wheel assembly. These devices appear in the lower part of Figure 7.

Mechanical driver aids, designed for persons with various degrees of physical handicap, have been donated by several manufacturers of this type of equipment. The equipment represents various designs of unknown efficiency and reliability. Each may be installed in the simulator and tested against performance without such equipment, or against the other alternative designs.

ELECTROMECHANICAL FEATURES

Evaluation of operator performance requires the measurement of (a) displacement, velocity, and torque applied to the steering wheel; (b) forces applied to the brake and clutch pedals; and (c) response time to complete manipulative tasks. Measurements are made with various electromechanical transducers. Position of the wheel is measured by a direct coupled potentiometer. Velocity and direction of rotation is proportional to the output of a DC tachometer generator. Applied torque is determined by a strain gage bridge mounted between the steering wheel and shaft.

Electrical signals from the transducers are fed into a computer, analyzer, and/or recorder.

The potentiometer and tachometer generator are driven by the steering shaft through a gear chain. A set of change gears provide steering shaft-to-transducer displacement ratios of 1:2, 1:1, and 2:1, mechanically altering the sensitivity of these elements.

The instantaneous forces applied to brake and clutch pedals are measured by strain gage-equipped load cells mounted directly beneath the pedal surface. The load cells measure applied force as a function of the output of a semiconductor strain gage bonded to a steel diaphragm. The gage acts as one leg of a conventional bridge circuit that is unbalanced when a force-induced strain exists in the diaphragm.

Response time will be recorded for all foot- and hand-operated devices.

Manipulation of these devices will activate microswitches connected to a 20-channel event recorder. The stimulus signals are also recorded.

A two-variable "pursuit" display is used, one variable representing the input (or desired output) and the other representing the actual output of the system. These variables are displayed on a dual-beam oscilloscope in the form of a dot (target) and a line (integrated operator output). Visual representation of the sum of four nonharmonically related sinusoids insures a random appearing motion of the target dot. The operator responds by manipulating the steering wheel which moves the vertical line at a rate proportional to the steering wheel displacement.

The tracking system devised for the laboratory is shown in Figure 8. Detailed information concerning the tracking system will be available in future publications.

Simulated inertia, stiffness, and damping (input impedance) of the steering system are controlled by the torque motor. Power is obtained from a servo-amplifier and amplidyne. The output from the potentiometer and tachometer are the inputs to the servo-amplifier. Simulated impedance can be varied by altering coefficients of the servo-amplifier.

To simulate greater steering wheel impedance than the torque motor can produce, a mechanical system of springs and weights has been added. Despite a slight loss of flexibility the resultant combined mechanical and electrical system provides greater range and accuracy of system response.

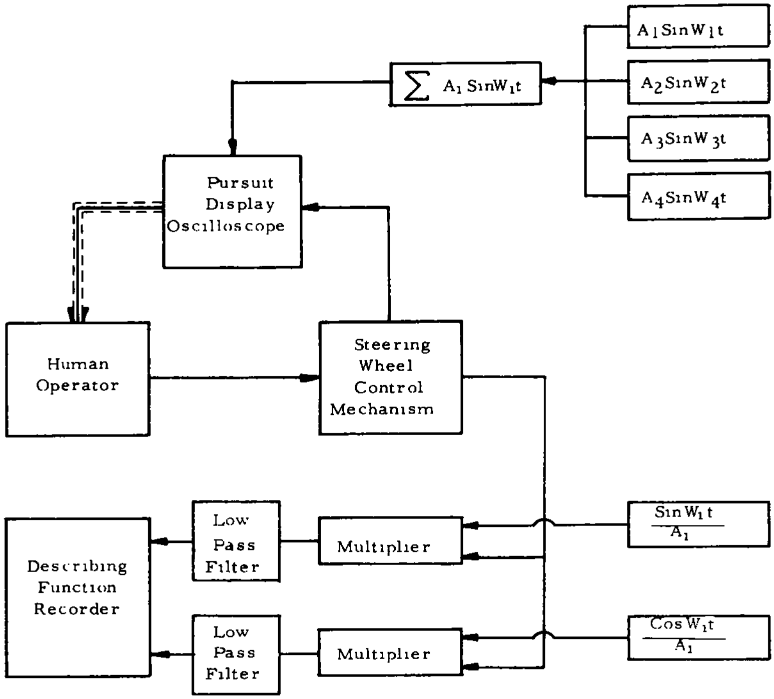

Figure 9. Schematic diagram of computation system for derivation of operator describing function.

A variety of disturbances can be superimposed on the torque motor input to simulate steering wheel shimmy or sudden wheel displacement. The operator can be made to experience kinesthetic stimuli characteristic of adverse road conditions, blowouts, and/or misaligned or unbalanced wheels.

DATA COMPUTATION

The description of human continuous control performance in servomechanism terminology has proven to be a powerful methodological technique. Consequently, time-varying mathematical-describing functions are continuously computed from the tracking data. In addition, conventional "error" scores will be computed. The combination of these performance measures will empirically define the operator's tracking behavior.

The electronic computation system developed for the derivation of operator describing functions is a modification and elaboration of Sheridan's apparatus which utilizes the orthogonal input multiplication method. A detailed description of the theory and techniques associated with this method is available in publications by Sheridan (3) and Briggs (4). Figure 9 shows the electronic system used in the simulator.

In principle, the output signals of the steering shaft potentiometer are multiplied by sine and cosine functions corresponding to the frequency components of the tracking display target. These products are then fed through a low-pass filter. The output of the low-pass filter is comprised of the orthogonal components of a vector which in turn specifies the operator gain and phase characteristics for each frequency. These performance parameters are continuously recorded and may be conveniently represented by a Nyquist or Bode diagram.

Standard statistical techniques are used to compare driver performance among individual subjects and between control and experimental groups under equivalent task complexity. Digital computers are used for the mathematical analyses.

ACCESSORY EQUIPMENT

Additional equipment useful in vehicle operator research projects is included in this section of the report:

Torque-Measuring Steering Apparatus

A second steering wheel and shaft assembly will be mounted on the right side of the operator's cockpit. This assembly will be rigidly anchored at the far end of the shaft on which is affixed a transducer. Thus, torque applied to the wheel can be directly measured by sending the transducer output to a torque meter which can be read directly. This apparatus was constructed because it was felt that an initial estimate of at least maximum, transient, human upper extremity output was necessary as a strength-of-response referent. The torque-measuring steering wheel is to be placed in the cab merely as an experimental convenience.

Enclosure and Shielding

Certain studies will require control over a wide range of environmental factors such as temperature, noise, illumination, interference from stray electrical fields and static, and general movement of personnel in and around the experimental situation. To control these kinds of variables at least partially, the entire mechanical apparatus is encased in detachable plywood panels, in turn shielded with overlapping aluminum screens. These precautions alone extend the range of potential use of the experimental facility.

Research Vehicle

General Motors Corporation has loaned for an indefinite period a Chevrolet station wagon. This has been instrumented to enable measuring responses to the steering wheel, and to brake, clutch, and accelerator pedals. There is a special detachable steering wheel that can be clamped into position that allows measuring torque. All data are recorded with a Mnemotron tape recorder. The tape data are then filtered through channel selectors, amplified, and recorded on continuous graph paper as visible. This equipment permits bridging the gap between laboratory and "real world" studies, at least to a degree.

Auxiliary Equipment

Certain commercial components were donated to the project by Chrysler Corporation, International Harvester Company, and Mack Trucks, Inc. In addition, manufacturers of handicapped driver aids who have donated their equipment for research are as follows:

Brake Center, Inc., Long Island City, N.Y.
Car Hand Controls, Garland, Tex.
Drive Master Corporation, Montclair, N.J.
Gresham Driving Aids, Detroit, Mich.
Holland Porter, North Long Beach, Calif.
Kroepke Manufacturing Company, New York, N.Y.
Leverage Hand-Brake Company, Fargo, N.D.
(donated two models, operating on two different principles)
Oldsmobile, Lansing, Mich.
Simdrico Corporation, Louisville, Ky.
Wells-Engberg Company, Rockford, Ill.

SUMMARY

The simulator may be considered a general human operator control laboratory. With minor modifications the apparatus can be made to accommodate a wide variety of technical human factors research problems. Studies need not be limited to vehicular control research, but may be designed to encompass a large area of the psychomotor and biomechanical behavior of the human operator.

ACKNOWLEDGMENTS

The project engineers who have designed and constructed the simulator are Donald Paterson, Thomas J. Crowley, and Benjamin C. Duggar. The electronic technician was Gervase R. Tinsley.

REFERENCES

1. McFarland, R.A., and Domey, R.G., "Bio-Technical Aspects of Driver Safety and Comfort." Annual Meeting, SAE (1958).
2. Kephart, N.C., and Dunlap, J.W., "Human Factors in the Design of Vehicle Cab Areas." Purdue Research Foundation, Occupational Research Center Psychology Department, Final Report (1953-1954).
3. Sheridan, T.B., "Human Operator's Time-Varying Transfer Characteristics in the Study of Perception and Fatigue." Paper, British Institution of Mechanical Engineers Symposium on Automatic Control (1960).
4. Briggs, P., "Measurement of Human Operator Alertness in Continuous Control Systems." DAC Laboratory, M.I.T., ERD-TN-60-794.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.