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ASHINGTON

U.S. Route 66, with frontage road construction, north of Joliet, Ill.

IN THIS ISSUE: An introduction to digital recording.

Public Road

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U.S. DEPARTMENT OF COMMERCE
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Driver Tension Responses Generated on Urban Streets

BY THE DIVISION OF TRAFFIC OPERATIONS
BUREAU OF PUBLIC ROADS

Reported[1] by RICHARD M. MICHAELS,
Research Psychologist

The purpose of this study was to relate driver tension responses to events in traffic which caused the driver to make an overt change in speed or lateral location of the vehicle being driven. In order to measure he tension responses the galvanic skin eflex (GSR) was employed. Ten driver-subjects were used on two urban test routes, and, over a 2-week period, each subject drove each route 25 times. The routes were driven during five traffic time periods, including peak, offpeak, and night.

The galvanic skin responses were measured continuously during each trip. The traffic events causing the responses were also determined independently by an observer and registered on the GSR record.

The results of the tests indicated that traffic events occurred at a rate of 1 every 1 to 35 seconds. Of these events, 85 percent generated a measurable galvanic skin esponse. It was also determined that of he measurable responses, 95 percent were aused by 8 types of traffic interferences: he most prevalent of which involved other ehicles in the traffic stream. This one ype of traffic interference accounted for over 60 percent of all responses.

IN most analyses of the operational characteristics of traffic on an urban street, the ndividual motor vehicle is usually undifferentiated from the whole of traffic. Instead, he factors determining the operations of the treet are inferred from certain physical measurements of the mass of traffic itself. There have been relatively few attempts to utilize driver behavior itself as a measure of traffic characteristics, or as a means for discriminatng among different streets (*1*,*2*).[2] In this study an attempt has been made to explore the possibility of using driver behavior as an instrument for the analysis of highway and traffic characteristics.

In developing a measure of driver behavior rom which it would be possible to draw inferences about the highways under study, two classes of questions were of particular interest:

- Are there stable characteristics of different streets that can be discriminated by some measure of driver behavior?
- Are there stable characteristics within a street and of the traffic on it which can be discriminated, using some measure of driver behavior?

The hypothesis which indicated the choice of behavioral measure was that the frequency and complexity of decisions required in driving on urban streets is so great that the driver is under a high level of tension. This hypothesis implies that the frequency and magnitude of tension responses aroused in driving will vary in some relation to the nature of the street and of the traffic.

Galvanic Skin Reflex

There are a variety of behavioral measures which may be employed to measure tension responses. However, for the purposes of this study it was desirable to have a measure that was directly relatable to events in traffic or the street on the one hand and also one that was a reliable indicator of driver tension response. A physiological measure that most nearly fulfilled these requirements is the galvanic skin reflex (GSR). This is a response occurring in the skin, manifesting itself as a change in the electrical resistance of the skin. The reflex is induced by activity of the autonomic nervous system and is initiated by unexpected stimuli that may be startling or tension inducing. The response appears as a decrease in skin resistance, and the magnitude of the reduction is correlated with the intensity of the inducing stimuli (*3*). Thus, the GSR represents one way to quantify the effects of an emotion-inducing stimulation.

An important characteristic of the GSR is its relation to the conscious experiences of the subject. It has been proved that there is a very high correlation between the GSR responses and the subject's awareness of the inducing stimuli (*4*)—a direct correspondence between the GSR itself and the event which caused its arousal. In general, the GSR is a means for quantifying those conscious experiences which arouse tension and, for the purposes of the study, this was ideal as it allowed a reliable relation of the emotional response to the traffic event which generated it.

Study Procedure

Two Washington, D.C., arterial streets served as test routes for this study. One route was a major arterial to and from the downtown Washington area. The second route paralleled and functioned as an alternate to the first route. Both were 4½ miles in length. The characteristics of each were quite dissimilar. Route No. 1 served a considerable number of traffic and commercial land-use functions that were not found on the alternate route. The alternate route ran primarily through a residential area, had almost no commercial traffic, and transit facilities were located on only a small portion of its length. In addition, the street width varied from two to four lanes over the 4½ miles. There was also considerable variation in both grade and curvature over this distance.

In order to relate galvanic skin responses to driving on the test routes, it was necessary to develop a list of types of traffic interferences since, in addition to the physiological measure of tension, it was necessary to specify the causes of these responses. This required establishing some criterion of what constituted an interference in driving.

Since the concern of the research was to relate street and traffic characteristics to driving behavior, it was decided that only those events which induced the driver to change either the speed or lateral location of the motor vehicle would be considered. This criterion implied that any change forced upon the driver was potentially tension inducing. An additional restriction imposed was that only the most direct cause of these changes would be classified as the inducing traffic event. Thus, for example, the driver might be in a stream of traffic which was forced to stop for a traffic signal. If the test vehicle were not the first to approach the signal, then the event which caused his change in speed was considered to be the vehicle in front of him rather than the traffic signal. Although such a distinction was arbitrary, it served two purposes. First, it reflected what the test driver directly responded to, even though he might have been aware of other events that were actually involved; and second, such a distinction greatly increased the reliability of observation.

This rationale oversimplifies the driving situation, for there was no question that the driver was aware of events considerably farther ahead than a car length. In addition, this system was limited in its ability to specify multiple and fast-changing situations.

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[1] This article was presented at the 39th Annual Meeting of he Highway Research Board, Washington, D.C., January 960.

[2] Italic numbers in parentheses refer to a list of references on page 71.

However, it was felt that reliability of observation was far more important than detailed specification of traffic interferences. From these considerations, a list of observed traffic events was developed. By code number, the observed tension inducing traffic interferences were:

1. *Parking maneuvers.*—Vehicles in the process of parking or already double parked.
2. *Marginal pedestrians.*—Pedestrians at or near the curb beginning to move into the street.
3. *Instream vehicles.*—Vehicles in the traffic stream in front of or adjacent to the test vehicle.
4. *Transit loading platforms* (route No. 1).—Loading platforms located in the street. *Opposing vehicles* (route No. 2).—Vehicles approaching the test vehicle from the opposite direction.
5. *Instream pedestrians.*—Pedestrians already in the street either directly in or approaching the path of the test vehicle.
6. *Diverging vehicles.*—Vehicles attempting to leave or disassociate from the traffic stream.
7. *Merging and crossing vehicles.*—Vehicles other than those in the stream of travel attempting to join or cross the traffic stream.
8. *Traffic signals.*—Traffic controls or signals which directly induced a change in the speed of the test vehicle.

The eight broad categories were determined in part by the nature of the street. Thus, on route No. 1, streetcar loading platforms were obvious interferences and were specifically included. On route No. 2, however, this was replaced by a medial friction event. In addition to being based on the actual nature of the study routes, these events were also predicated upon certain friction concepts of traffic flow. As may be seen, the list is a compromise between the general case of four frictions and the more specific individual conflicts that occur in traffic.

For the conduct of the experiment, a passenger car with automatic transmission was used. Study teams consisted of a driver, an observer, and a recording instrument operator. The observer served as the team leader during the experiment. It was the duty of the observer to specify when a traffic event occurred and which event caused the change in vehicle operation. These were reported to the instrument operator who was seated in the rear seat of the vehicle. He in turn coded the information on the GSR recorder, and was the only member of the team to have knowledge of the driver's responses.

The drivers were instructed to travel the route by floating with the traffic wherever possible. With these instructions, the general pattern of driving was quite consistent among the test drivers. Although some differences in driving patterns and driving habits were noted, the differences were generally quite minor and ordinarily very subtle.

At the outset of the test run, electrodes were placed on the first and third fingers of the left hand of the test driver. Although a variety of electrode placements were tried, it was found that placement on these two fingers gave the most sensitive response, were mechanically the simplest to place, and allowed the driver to operate the vehicle normally. After placement of the electrodes, a normal resting level (that is, a basal level) for skin resistance was determined. The recording machine contained a feedback circuit for balancing out drift in the basal level. Thus, only deviations from an arbitrary zero level were measured.

The sensitivity level for each driver was adjusted empirically at the beginning of the test run. Usually a startle stimulus was employed and the sensitivity raised until the full scale of deflection was obtained. For all drivers the required sensitivity range was quite narrow. Determining the sensitivity range did not, of course, eliminate individual differences among the drivers, but it did reduce the variability for an individual driver from run to run.

Two phases of study

The study was conducted in two phases. First, each of the five test drivers drove both routes in one continuous cycle, and the differences between the two routes were compared. For these runs four complete cycles were obtained for each driver during the offpeak traffic hours.

In the second phase, each route was studied individually during five workday traffic periods. The runs were made during the morning peak hour traffic, morning offpeak traffic, afternoon offpeak traffic, afternoon peak hour traffic, and nighttime traffic. Each of the five drivers drove a complete cycle of each route three times during the peak hours and twice during the offpeak hours. The design was to have each driver observed an equal number of times by the two different observers.

In either phase of the study, at the beginning of the run, the time was noted and the drivers floated with the traffic from one end of the route to the other. The observer reported to the instrument operator any changes meeting the criteria of traffic interference and what events caused the change. At the end of the route there was a 10-minute rest durin which time the basal level of skin resistan was again determined. Usually there was slight increase of level from the beginning t end of the route, especially on the first ru After the rest period, the driver proceeded t complete the full cycle.

Data recorded

Observers were instructed to report even to the instrument operator as quickly as po sible in order to minimize errors in locatin occurrences in time on the GSR record. sample record of the galvanic skin response figure 1, shows that a notation was generall placed simultaneously with or slightly prece ing the response. Whenever an observatio preceded a response by more than 5 second the two were considered unrelated. Similarl an observation that followed a response b more than 1 second was considered unrelate to the response. Both these criteria we predicated upon the assumption that the la in the GSR response was longer than for th verbal response. In practice, uncertainty association of observation and response o curred in no more than 5 percent of th occurrences.

As may be seen from figure 1, some response were not associated with traffic events, suc as the small peak prior to the first event (even No. 7), and were not included in the analysi The GSR is sensitive to a variety of events, i ternal as well as external, so that unidentifiabl responses were fairly common. Also, a GS did not occur every time there was a traffi event, as exemplified in the case of the las event (event No. 3). Nevertheless, thes were included in the data analysis. It wa found that approximately 15 percent of th traffic events observed aroused no respons on the part of the driver.

Magnitude of GSR

The meaning of the magnitude of the gal vanic skin response needs some explanatio The recorder actually measures the GSR i

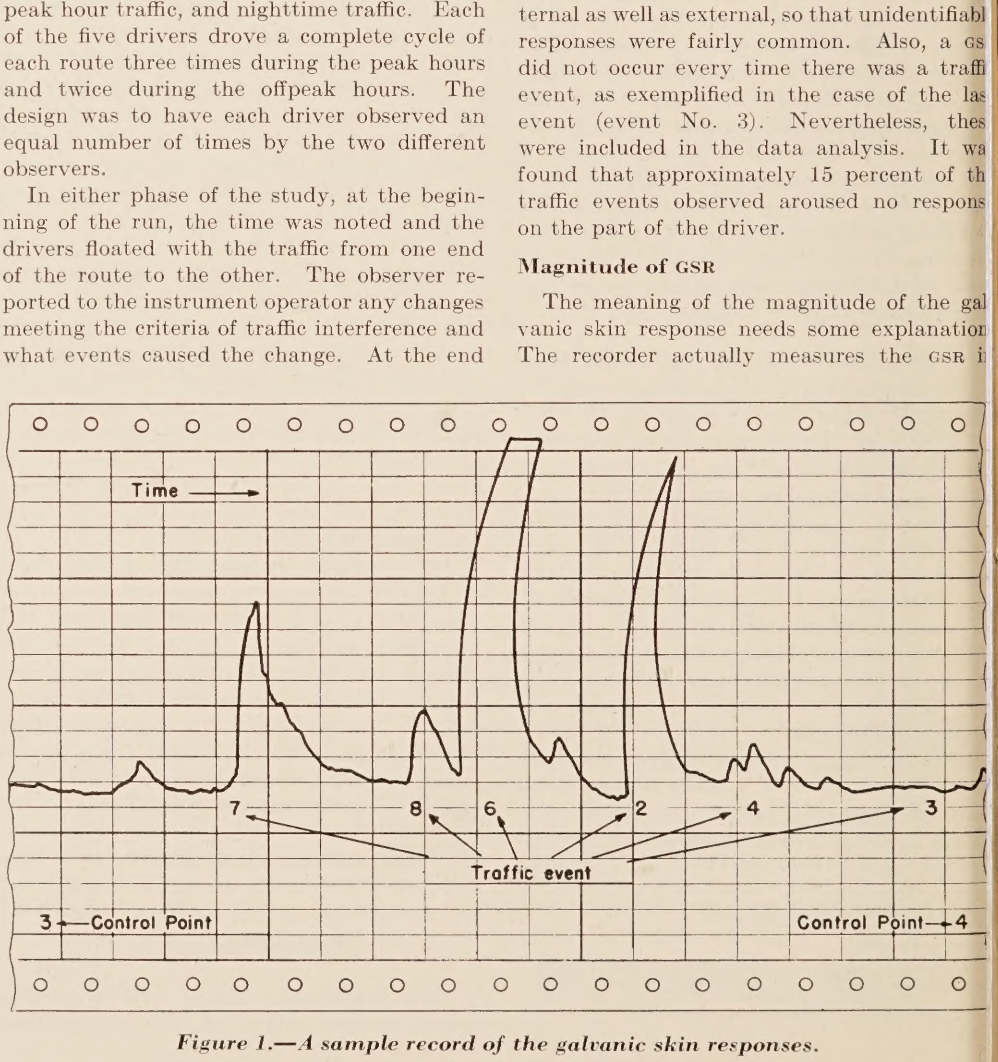

Figure 1.—A sample record of the galvanic skin responses.

units of log conductance. This unit is employed because the magnitude of change in skin resistance is more nearly linearly related to the magnitude of the inducing stimulus when resistance is measured in log conductance (*5*). Thus, the successive vertical divisions on the recorder chart represented equal increments of GSR. However, the absolute values of these divisions were not known, for these depended upon the setting of the sensitivity scale. With the method of calibration used, the values for each scale division were essentially relative to the base level. They are, as a consequence, unitless, and may be termed "reaction units."

Table 1.—Comparison of tension responses recorded in the continuous test run over both routes, made during offpeak traffic periods

	Route No. 1	Route No. 2
Total events	445	237
Events per minute	2.42	1.71
Average GSR magnitude	2.28	2.23
Magnitude response per minute	5.52	3.81

Test Results

The data were tabulated for each driver for each run and each route, and were broken down by the observed traffic events and the magnitude of response associated with each event. In addition, the travel time for each trip was recorded. It was possible from these data to determine the average magnitude of response for each event, and with the time measures to determine both the rate at which events occurred and the magnitude of responses that occurred in time.

Analyzing the data recorded during the continuous test run over both routes, study phase No. 1, table 1 contains the frequency of occurrence of events and the average magnitude of response for each event. In this tabulation the data for all drivers were combined. The difference in the total number of events in part reflects the difference in travel time for the two routes. In order to better equate the routes, a rate figure was computed and is shown in the table as the events per minute. Here it may be seen that the difference between the two routes are reduced somewhat. Nevertheless, there were still 42 percent more responses per unit time on route No. 1 than on the alternate route. On route No. 1 there was a traffic event once every 24.7 seconds while on route No. 2 there was an event every 34.9 seconds. Since 85 percent of the events aroused the GSR, there was, consequently, a tension inducing event every 29.2 seconds on route No. 1 and 41.4 seconds on the alternate. It is quite evident from these data, then, that drivers on the alternate route faced considerably fewer interferences with driving than on the major arterial route.

These results reflect only the frequency of occurrence of events and do not directly relate to the magnitude of the galvanic skin responses. The average magnitude of response alone was inadequate since it did not reflect the differences in travel time for the two routes. One simple measure is the total magnitude of response that occurs per unit of driving time. This measure cumulates all the galvanic skin responses independently of events and equates the routes on the basis of time. This ratio is, therefore, a statistic reflecting the behavioral response of the driver per unit time and under the assumptions of this study was considered as a measure of induced tension. From table 1 it may be seen that route No. 1 was 45 percent more tension inducing than the alternate route.

In order to test for differences among drivers as well as to determine whether there was a statistically significant difference between the two routes, the statistical technique of analysis of variance was used. A summary of the analysis is shown in table 2. Statistically, both the routes and the drivers differed significantly at the 0.01 level. It would seem reasonable to conclude, therefore, that the alternate route induced significantly less tension in drivers than did the major arterial route. In addition, the combining of the data of the different drivers appears to be unwarranted. This is especially relevant to the GSR data shown in table 1 where average magnitude of the GSR appeared the same for the two routes. Actually, the average magnitude showed considerable variation among the drivers, and the differences in average magnitude of each driver between the routes varied over a range of nearly two-to-one. Thus, the averages shown are quite misleading and, consequently, the combined GSR data must be interpreted with caution.

Table 2.—Summary of analysis of variance of the magnitude of GSR per minute for the test routes

Sources of variance	Sum of squares	Degrees of freedom	Mean square S^2	Variance ratio *F*
Route	19.57	1	19.57	[1] 11.51
Drivers	302.05	3	100.68	[1] 59.22
Routes and drivers	22.89	3	7.63	[2] 4.48
Residual variance	16.95	10	1.70	--------
Total variance	361.46	17	--------	--------

[1] Significant at the .01 level. [2] Significant at the .05 level.

Route No. 1

In addition to the study of the continuous runs made over the two routes, each route was studied independently. On the major arterial route, tabulating the occurrence of the traffic events, there was a total of 7,800 traffic events observed during the 2-week period. Data classified by the eight types of traffic event are presented in table 3. The most frequently occurring event was friction with instream moving vehicles. The remainder individually form small proportions of the total. In the last column of the table, the relative rank of each type of traffic event is shown for the average magnitude of GSR which it generated.

To test the reliability of the average magnitude of response, a rank test was applied using the data for each driver independently. In other words, the response generated by each traffic event, for each driver, was ranked and tested. The order shown in table 4 was found to be statistically reliable at better than the 0.01 level.

Data collected during the different traffic periods were also analyzed by direction. It was found that there was considerable variation among the runs made during peak hours and offpeak hours. Table 4 shows the average

Table 3.—Frequency of occurrence and average magnitude of responses evoked by traffic events on route No. 1

No.	Traffic event	Number of events	Percent of total	Average magnitude	Rank by average magnitude
1	Parking maneuvers	724	9.2	2.47	6
2	Marginal pedestrians	330	4.2	1.51	8
3	Instream vehicles	4,682	59.7	2.49	5
4	Loading platforms	633	8.0	2.20	7
5	Instream pedestrians	372	4.7	2.76	4
6	Diverging vehicles	400	5.1	3.34	1
7	Merging and crossing vehicles	285	3.6	3.15	2
8	Traffic signals	416	5.3	2.94	3
	All events	7,842	99.8	2.53	--------

Table 4.—Effects of traffic period and direction on the average magnitude of response for route No. 1

No.	Traffic event	Northbound			Southbound		
		Offpeak	Peak	Difference	Offpeak	Peak	Difference
1	Parking maneuvers	2.59	2.37	−0.22	2.25	2.87	+0.62
2	Marginal pedestrians	1.10	1.57	+.47	1.88	1.98	+.10
3	Instream vehicles	2.51	2.47	−.04	2.36	2.64	+.38
4	Loading platforms	2.09	1.45	−.64	2.27	3.15	+.88
5	Instream pedestrians	2.63	3.32	+.69	2.29	2.80	+.51
6	Diverging vehicles	3.64	2.86	−.78	3.37	3.49	+.12
7	Merging and crossing vehicles	2.97	3.13	+.16	2.50	3.96	+1.46
8	Traffic signals	3.11	3.67	+.56	2.25	2.65	+.40
	All events	2.50	2.52	+.02	2.36	2.77	+.41

magnitude of response and the changes from offpeak to peak period that occurred in each direction. The plus sign indicates that the response increased during the peak hours, whereas the minus sign shows that it decreased.

For the northbound direction there was almost no difference in average magnitude of response between offpeak and peak runs. In general, the data obtained in the northbound direction were more stable than the data obtained from the southbound runs. Consequently, the differences between peak and offpeak periods are most clearly seen for the former. The greatest increase in response during the peak hours appeared to be in the average tension induced by instream pedestrians (event No. 5). This was consistent with the increase in mass transit use during the peak hours and, consequently, the high density of pedestrians at loading platforms during those hours. Major decreases occurred in the turning movements out of the traffic stream (event No. 6). This, in part, reflects a reduction in the allowable turning movements during peak hours.

The average tension response for all events recorded in the southbound runs increased appreciably from the offpeak to the peak period. The greatest increase occurred in connection with merging and crossing vehicles (event No. 7). Because of the wide variability in the data, only qualitative interpretations are possible.

The analysis of test runs made during night traffic (data not shown here) appeared to follow the pattern derived from the analysis made during the day peak hours. The most obvious differences were in the northbound direction. The only major change at night appeared to be the large increase in response to marginal pedestrians (event No. 2). This was perhaps due to the large increase in pedestrians during evening shopping hours and also the restriction in marginal visibility over much of the street.

Analyzed by control sections

Route No. 1 was divided for analytical purposes into nine control sections of approximately equal length. The 10 control points (for these nine sections) were marked on the recorder tape so that it was possible to relate the events to their location on the route. Table 5 shows the average magnitude of GSR tension response for each section both by direction and traffic period. In addition, figures 2 and 3 show the mean magnitude of tension response by control sections. Generally, there was considerable variability in the data within a section, while the differences between sections were, on the average, not too great. There was no significant order of tension responses found among the sections for the five test drivers. Thus, there was no indication that there were fixed features in any of the sections which consistently influenced driving behavior.

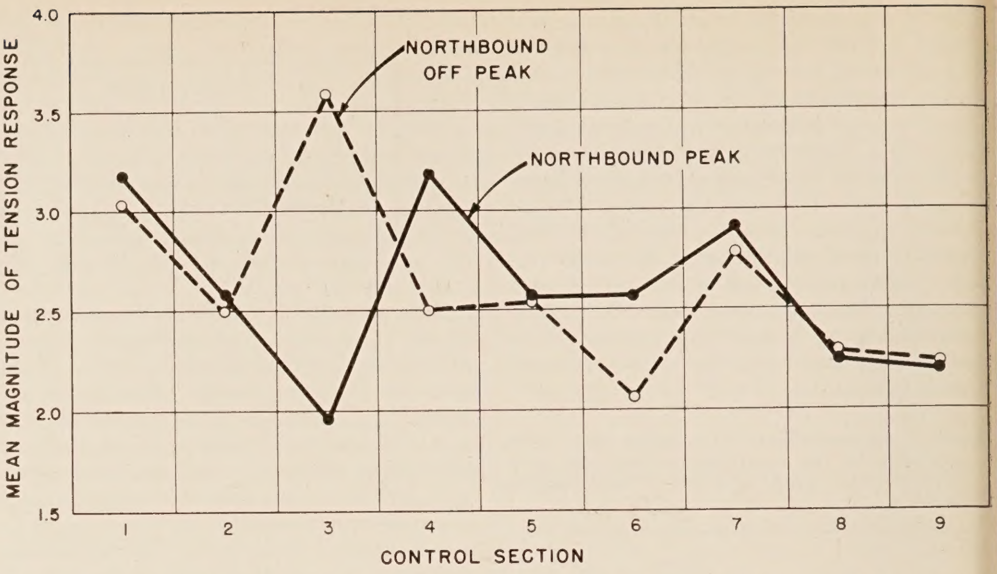

Figure 2.—Average magnitude of tension responses for each control section while traveling in the northbound direction.

As may be seen from figure 2, the differences between peak and offpeak were quite small for all control sections except in section 3. During the offpeak hours this section gave the maximum average tension response, whereas during the peak hours it yielded the lowest average tension response. In order to test for the significance of this difference, a t test was made of each driver's tension responses in peak and offpeak traffic (a t test of matched pairs). Since it was found that the decrease from offpeak to peak was significant at better than the 0.05 level, a real change in traffic characteristics apparently occurred in control section 3. This was an area of intense commercial development and also an area where the street was relatively narrow. During the offpeak hours there was a high degree of marginal activity related to the commercial development. Also, reduced maneuverability due to the narrowness of the street posed a severe restriction on the driver's freedom to make lateral avoidance movements. During peak hours, however, the extensive marginal friction was eliminated. Parking regulations, high traffic volume, and signal progression helped to minimize turbulence in the traffic flow.

In the southbound direction there were no clear-cut differences between either traffic period or control section, as may be seen from figure 3. In control section 7 there did appear to be a maximum average tension response during the offpeak hours. This section was located in a highly developed commercial area and there was considerable marginal activity, complicated by turning movements into and from radials at a traffic circle. The peak hours, aside from showing a general rise in tension responses, did not indicate any major differences among the control sections.

Table 5.—Average magnitude of responses in the control sections of route No. 1, by direction and traffic period

Control section	Northbound			Southbound			Difference between northbound and southbound	
	Offpeak	Peak	Difference	Offpeak	Peak	Difference	Offpeak	Peak
1	3. 04	3. 18	−0. 14	2. 34	2. 34	0. 00	+0. 70	+0. 84
2	2. 50	2. 58	−. 08	2. 36	2. 99	−. 63	+. 14	−. 41
3	3. 58	1. 95	+1. 63	2. 47	2. 86	−. 39	+1. 11	−1. 91
4	2. 50	3. 18	−. 68	2. 18	2. 78	−. 60	+. 32	+. 40
5	2. 56	2. 55	+. 01	2. 37	3. 15	−. 78	+. 19	−. 60
6	2. 05	2. 57	−. 52	2. 71	2. 89	−. 18	−. 66	−. 32
7	2. 78	2. 90	−. 12	2. 82	3. 07	−. 25	−. 04	−. 17
8	2. 28	2. 25	+. 03	2. 66	2. 76	−. 10	−. 38	−. 51
9	2. 23	2. 20	+. 03	2. 48	3. 06	−. 58	−. 25	−. 86

Frequency of tension responses

The final analysis of the route No. 1 data involved the determination of a relative frequency of traffic events and the total GSR per minute. The pertinent data are shown in table 6. These data, which included all the runs for each of the drivers, indicated that there were fewer events per minute in northbound traffic than in southbound traffic. In northbound traffic, the driver encountered an event every 25.0 seconds, while traveling in the southbound direction the driver encountered a traffic event every 21.3 seconds. Tension inducing events were encountered every 29.4 seconds northbound and 25.2 seconds southbound. In terms of the measure of induced tension, the magnitude of GSR per unit time, the differences between the two directions were on the whole quite small and there appeared little evidence to indicate significant differences in the two directions. The drivers also reported that they found no differences between directions.

Route No. 2

In the study of the alternate route (route No. 2), a different group of driver-subjects were employed, as well as one new observer. This route had great variation in grade and

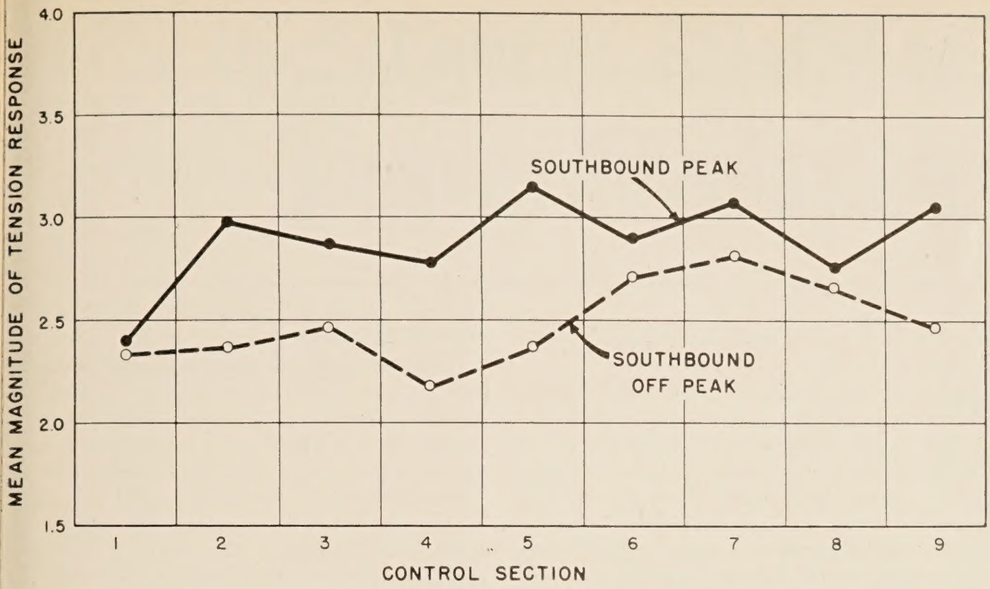

Figure 3.—Average magnitude of tension responses for each control section while traveling in the southbound direction.

width over the 4½-mile length. Unlike route No. 1, there were no streetcars but bus service was in operation in sections of the route. Also in direct contrast to route No. 1, there were no commercial areas. The route was almost wholly through a residential area, consisting for the most part of single-unit dwellings. Again in contrast to route No. 1, where commercial vehicles made up a considerable portion of the traffic, almost all the motor vehicles traveling route No. 2 were passenger cars.

The study method followed for route No. 2 was the same as that used on route No. 1. One change was made in the list of traffic events—the elimination of transit loading platforms and the insertion of opposing vehicles (event No. 4). This event was added because the route was two or three lanes over much of its length. Consequently, there were many possibilities for the opposing traffic stream to come into conflict with the test vehicle.

The number of traffic events and the frequency of occurrence is given in table 7. More than 1,300 traffic events were observed during the study period, and as occurred on route No. 1, the most frequently occurring event was that induced by other vehicles in the traffic stream (event No. 3). The remainder of events individually accounted for only small proportions of the total. Moving vehicles constituted a 6-percent greater part of the total on the alternate route than on the major arterial route. Making the arbitrary assumption of homogeneity, a *t* test of the differences between the two proportions was made. A *t* of 4.21 was obtained which was significant at the 0.01 level. This would appear to indicate that the tension inducing characteristics of the alternate route seemed to include a lesser proportion of peripheral events than that found on route No. 1. Thus, most traffic conflicts on the alternate route appeared to be somewhat more directly related to instream traffic activity.

The ranking of the events according to the average magnitude of response in table 7 shows that the most tension-inducing traffic event was crossing and merging traffic (event No. 7). Opposing vehicles (event No. 4) was second highest in average magnitude of response. In general, the order of intensity of tension induction for each of the events was similar to that found on route No. 1.

The data are shown for the different traffic periods in table 8. The morning offpeak runs are not included in this tabulation as they were made in conjunction with the continuous test runs made on both routes. The overall frequency of occurrence of traffic events was 1.79 per minute, or approximately one every 33 seconds, with a minimum during the morning peak traffic hours of 1.45 events per minute, or one every 41 seconds. The frequency maximum was during the afternoon offpeak traffic hours when there were 2.65 events per minute, or one every 23 seconds. The maximum tension response per minute occurred during the afternoon offpeak hours and was twice as great as the response per minute for either of the peak hour traffic periods. Tension responses per minute for the night runs fell intermediate between the peak and offpeak traffic periods. It should be pointed out, however, that these differences were obtained by pooling data from drivers who were dissimilar in their tension responses. They should, consequently, be interpreted carefully.

Discussion of the Findings

As was pointed out earlier, the purpose of the study was to explore the possibility of using the galvanic skin response as a means for distinguishing features of traffic and streets. The first goal was to detect differences between two arterial routes serving approximately the same traffic function. The results indicated that the GSR reliably discriminated between the two arterial routes, but the distinctions among different characteristics within each route were not as clear cut. However, the results do indicate the complexity of decisions faced by drivers on an urban street. The variety of conflicts occurring on the street were sufficiently frequent and involved to place drivers under a fairly consistent frequency of stress.

One finding of particular interest was, in terms of the average magnitude of GSR, the significant order of the different traffic events. The events which induced the highest average tension on both routes were the conflicts occurring with vehicles entering or leaving the traffic stream and, on the alternate route, the opposing vehicles. These were events in which the rate of change of location of the conflicting vehicles was at a maximum. These were situations where the driver was required to solve a set of differential equations in order to predict a course of action. With the human's limited accuracy in speed esti-

Table 6.—Traffic events and magnitude of tension responses in time on route No. 1

Driver	Events per minute			Magnitude of response per minute		Ratio: northbound / southbound
	Northbound	Southbound	Difference	Northbound	Southbound	
A	2.4	2.9	+0.5	7.30	7.60	0.96
B	2.1	2.5	+.4	6.59	8.30	.79
C	2.7	3.1	+.4	6.91	6.60	1.05
D	2.6	2.7	+.1	4.11	3.81	1.08
E	2.3	2.7	+.4	6.90	9.40	.73
All drivers	2.4	2.8	+.4	6.29	7.23	.87

Table 7.—Frequency of occurrence and average magnitude of responses evoked by traffic events on route No. 2

No.	Traffic event	Number of events	Percent of all events		Average magnitude	Rank by average magnitude
			Route No. 2	Route No. 1 [1]		
1	Parking maneuvers	70	5.3	9.2	1.30	8
2	Marginal pedestrians	9	0.6	4.2	1.56	7
3	Instream vehicles	863	65.6	59.7	1.77	5
4	Opposing vehicles	50	3.8	[2] 8.0	2.14	2
5	Instream pedestrians	17	1.7	4.7	1.71	6
6	Diverging vehicles	70	5.3	5.1	1.79	4
7	Crossing and merging vehicles	93	7.0	3.6	2.58	1
8	Traffic signals	142	10.8	5.3	1.97	3
	All events	1,314	100.1	99.8	1.84	--------

[1] Data from table 3. [2] Event No. 4 on route No. 1 was transit loading platforms.

mation and angular closing rate, and the limited time for such decision, these situations had a high degree of unpredictability for the driver and may reasonably be most threatening.

The two events which ranked next in order were the traffic signals and instream pedestrians. Both may be considered as "instream uncertainty." In the study, the driver was influenced by traffic signals only when there were no other vehicles interposed between him and the signal. There was, then, a fairly high probability that the driver arrived at a signal at the moment when it had just changed or was in the process of changing. This would appear to be a particularly indeterminate situation for the driver. The effect of instream pedestrians was quite similar. The driver had no way to predict the action of a pedestrian. Any conflict would arise strictly by action of the pedestrian. Both events probably represent a straight risk-type decision operation, and the observed magnitude of tension response may well reflect the degree of uncertainty in each situation.

A third pair of traffic events which appear to go together are the instream vehicle and parking maneuver events. These both may be considered "instream interferences." In the instream vehicle event, the vehicles were moving in the same direction and the relative differences in velocity between the test vehicle and other vehicles in the stream was relatively small. Consequently there was adequate time for compensation for any changes in the characteristics of the ongoing traffic stream. Parking maneuvers were generally found to be quite conspicuous so that the test driver was able to adapt his speed or direction with relative ease. Both events appeared to be relatively predictable actions for which the driver could adequately compensate, and for which there was adequate time for decision making.

The last two traffic events, marginal pedestrians and the streetcar loading platforms, may be termed "fixed objects." For all cases observed, conflict between pedestrian and vehicle occurred when the pedestrian was standing or just beginning to move into the street. At this point it seems reasonable to consider this as a fixed-obstacle situation. In general, it appeared in both of these types of events that the driver had more or less complete control over his actions. Thus, these events may be conceived as simply choice points, and the responses were a reflection of tension stress due to a choice made by the driver.

Predictability and response

One general implication from the results of the study is consistent with current knowledge of the GSR. It is that the more highly unpredictable the situation, the more dynamically the subject responds. The unique thing in the study was the fact that there appeared to be a very high level of unpredictability in driving on urban streets. The data indicated that about three times a minute an event occurred which forced the driver to take some compensatory action. Furthermore, as the traffic situation created a more complex demand upon the driver, the tension aroused by that situation became even greater.

Table 8.—Frequency of occurrence and average magnitude of response on route No. 2 by time period

Traffic period	Number of events	Average magnitude of response	Events per minute	Magnitude of response per minute
Morning peak	292	1. 68	1. 45	2. 44
Afternoon peak	363	1. 41	1. 86	2. 62
Afternoon offpeak	122	1. 98	2. 65	5. 25
Night	346	2. 21	1. 89	4. 18
All traffic	1, 123	1. 79	1. 79	3. 20

These results indicate that the driving environment generates a tension response in inverse relationship to the predictability of the conflicts. The ranking order of the traffic events significantly demonstrates the situations which are hardest for the driver to predict and thus to compensate for. Also, the complexity of the driving environment may be added to the element of predictability. In the only control section where there was a significant difference between traffic time periods, the decrease in average GSR came when the complexity of the traffic situation was reduced.

In addition, the differences between the two arterial routes, in terms of their percentage of marginal interferences, also indicated a difference in complexity between the two routes. On route No. 1 over 40 percent of all observed events arose from interferences occurring along the margins of the street. In such a traffic situation the driver is forced to attend to a wide range of stimuli. He must sort, select, and then operate on this heavy load of information. His ability to select and predict is inherently restricted; one consequence of which is an increased level of stress and a greater tension response to events.

Delegation of control to other drivers

Finally, analyses of the findings indicated a high rate of decision making for drivers on an urban street. Where the driver was forced to respond to a fixed object the average GSR was relatively low. This was a situation where the driver usually made the decision on his own terms in his own time. In the situation of vehicles entering or leaving the traffic stream, the driver was forced to make decisions both very rapidly and with a minimum amount of information, much of which he could not handle accurately or efficiently. Under these circumstances the driver was dependent upon other drivers to respond consistently. In complex traffic, then, the individual driver was often forced to give up a certain amount of control to other drivers in the traffic stream.

As to how this delegation of control would affect traffic operations and capacity, it appears reasonable to believe that a driver will compensate for this loss of control by any means at his disposal that will reduce his uncertainty. He can, for example, increase the headway between himself and the vehicle ahead, or by reducing his speed. Such compensations, however, have a tendency to reduce the capacity of the street, and cause turbulence in the flow of traffic.

Reliability of the GSR

The results of the study indicated that the GSR was an adequate measure of driver behavior. There were, however, questions relating to the GSR which have not been discussed in this article. One thing that needs to be examined far more intensively is the reliability of the galvanic skin response (*6*). It is well known, for example, that there is a rather consistent adaptation of the GSR so that the same stimulus intensity may not arouse the same magnitude of GSR on repetition (*7*). This was in part compensated by the calibration procedure used in the study, and the fact that no traffic event occurred twice in precisely the same way. Nevertheless, the changes which occurred during a test run were not examined in detail.

Some very simple assumptions have been made about the relation of the tension responses to the traffic situations. The problem is essentially one of determining what the responses mean in a traffic situation. It is an oversimplification to assume, as was done in this study, that the GSR is aroused only by the occurrence of a traffic event. The GSR is sensitive to a wide variety of behavioral responses (*8*) whose relationships may be only indirectly related to the traffic event. There is little doubt, for example, that the GSR accompanies preparatory muscular activity or muscular response itself (*9*).

Statistical significance of a tension response

Another problem is the statistical nature of the galvanic skin reflex. In the study the magnitude of response was a positively skewed distribution. The range of conductance was from zero to some maximum value. Such distributions pose some difficult problems of statistical analysis. Thus, in this study, the use of the arithmetic mean and the usual statistical tests of inference are in question.

There are also certain methodological problems of specifying and interpreting the traffic events. For the purposes of this study each traffic event was treated as discrete or isolated. It is obvious, however, that conflicts in traffic are not discrete but develop continuously in time. Thus, the schedule of observation arbitrarily collapsed a complex and continuous behavioral response to a single point in time. There is no way of knowing from the present study whether an observed galvanic skin response occurred at the approach to a conflict, during the conflict itself, or at the point in time when a decision was made. It is conceivable that any or all of these processes could evoke a response.

(*Continued on page 71*)

Traffic Operations as Related to Highway Illumination and Delineation

A Cooperative Investigation by the Connecticut State Highway Department and the Bureau of Public Roads

Reported [1] by
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The increasing mileage of freeways being put into operation has stimulated much discussion of highway illumination and its possible value in reducing the tension and strain of night driving and in reducing traffic accidents, and perhaps thereby increasing the night usage of these highways. Because of lack of factual knowledge on the subject, the Connecticut State Highway Department in cooperation with the Bureau of Public Roads undertook a study of the effects of illumination and delineation on the Connecticut Turnpike. Driver behavior data were recorded under nine different conditions of highway illumination and delineation at a heavily traveled interchange illuminated with mercury lamps. Accident data were obtained on the 53-mile continously illuminated section and the 77-mile nonilluminated section of the Turnpike.

The study showed no significant differences with respect to average vehicle speeds, lateral placements, and clearances between vehicles, under the various conditions of illumination and delineation. The manner of night usage of speed change lanes, particularly the acceleration lane, improved with increased illumination. In general, it appeared that some benefit resulted from full-level illumination in the deceleration area, and that even greater benefit occurred when illumination was combined with roadside delineation. Illumination of the interchange area only did not appear to be advantageous insofar as the access ramp site was concerned. The importance of delineation, with or without illumination was demonstrated.

TRAFFIC at night has always had accident rates averaging about twice that of day-ime rates, and the rapid, continuing growth of travel has increased both the awareness of the magnitude of this problem and the efforts o develop remedial measures. Night driving nvolves not only the problems of darkness, but hazards of fatigue, drowsiness, and other actors. The ultimate solution in avoiding darkness, of course, would be to illuminate he roadways to the same intensity as exists during daylight, but this is obviously impractical. It remains to be determined, therefore, what level of illumination would induce drivers to operate their vehicles at night in the ame manner as they do during daytime.

While it has been an accepted fact that good visibility is a prerequisite to good traffic operations, there have been no accredited warrants set forth for highway lighting. Similarly, there has been no correlation between the effects on traffic operations of deineation (reflector buttons) and illumination.

Scope of Study

The importance of highway lighting was emphasized at the 1958 annual meeting of the Highway Research Board and again at the 1959 annual meeting of the American Association of State Highway Officials. Because very little was known on the effectiveness of highway lighting on freeways, with respect to driver behavior, accidents, and night usage of the highway, the Connecticut State Highway Department in cooperation with the Bureau of Public Roads undertook a comprehensive study in this field in 1959. Continuous modern highway lighting on a 53-mile section of the 129-mile Connecticut Turnpike afforded a good opportunity to investigate the effects of illumination and delineation on traffic operations.

The purpose of the study was to evaluate the effectiveness of roadside delineation, pavement markings, and a combination of delineations and markings under conditions of full, partial, and no highway lighting. The effects to be ascertained would be those manifested in accidents, and in drivers' actions such as speed, lateral placement, headway distance, lane usage, and utilization of acceleration and deceleration lanes. A total of 183,000 motor vehicles were observed under the following nine principal lighting conditions:

No illumination:

1. Lane lines only.
2. Lane lines and edge lines.
3. Lane lines, edge lines, and roadside delineators.

Partial illumination:

4. Lane lines, edge lines, and one-half normal illumination.
5. Lane lines, edge lines, delineators, and one-half normal illumination.
6. Lane lines, edge lines, delineators, and one-half normal illumination in interchange area only.

Full illumination:

7. Lane lines, edge lines, delineators, and normal illumination in interchange area only.
8. Lane lines, edge lines, and normal illumination.
9. Lane lines, edge lines, delineators, and normal illumination.

The white reflectorized lane lines were dashed, with both dashes and spaces being 25 feet in length. All edge lines were reflectorized; solid white to the left of the traffic stream and solid yellow to the right. The lane and edge lines were 6 inches in width on the Turnpike proper, and 4 inches in width on the access and exit ramps.

Highway lighting consisted of mercury luminaires throughout. Delineation consisted of acrylic plastic reflex reflectors, 3 inches in diameter, mounted at a height of 4½ feet above the pavement. The reflectors were spaced at 200-foot intervals on the Turnpike and at reduced intervals on the access and exit ramps. They were placed about 12 feet from the pavement edge on the shoulder and about 5 feet from the pavement on the median strip. Installations on the Turnpike consisted of single white reflectors on both sides of the roadways, whereas dual amber reflectors were used on both sides of the ramps.

Locations Studied

Although originally planned procedures included a number of study sites, preliminary work indicated the necessity for simplification of the study program if it was to be completed within a reasonable time period. Two comparable sites were selected for detailed study, located at a Turnpike interchange with large volumes of traffic. Site 4M was located on the access ramp and site 5M on the exit ramp. From all the sites originally selected for study, it was presumed that site 4M and

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[1] This article was presented at the 39th Annual Meeting of the Highway Research Board, Washington, D.C., January 1960.

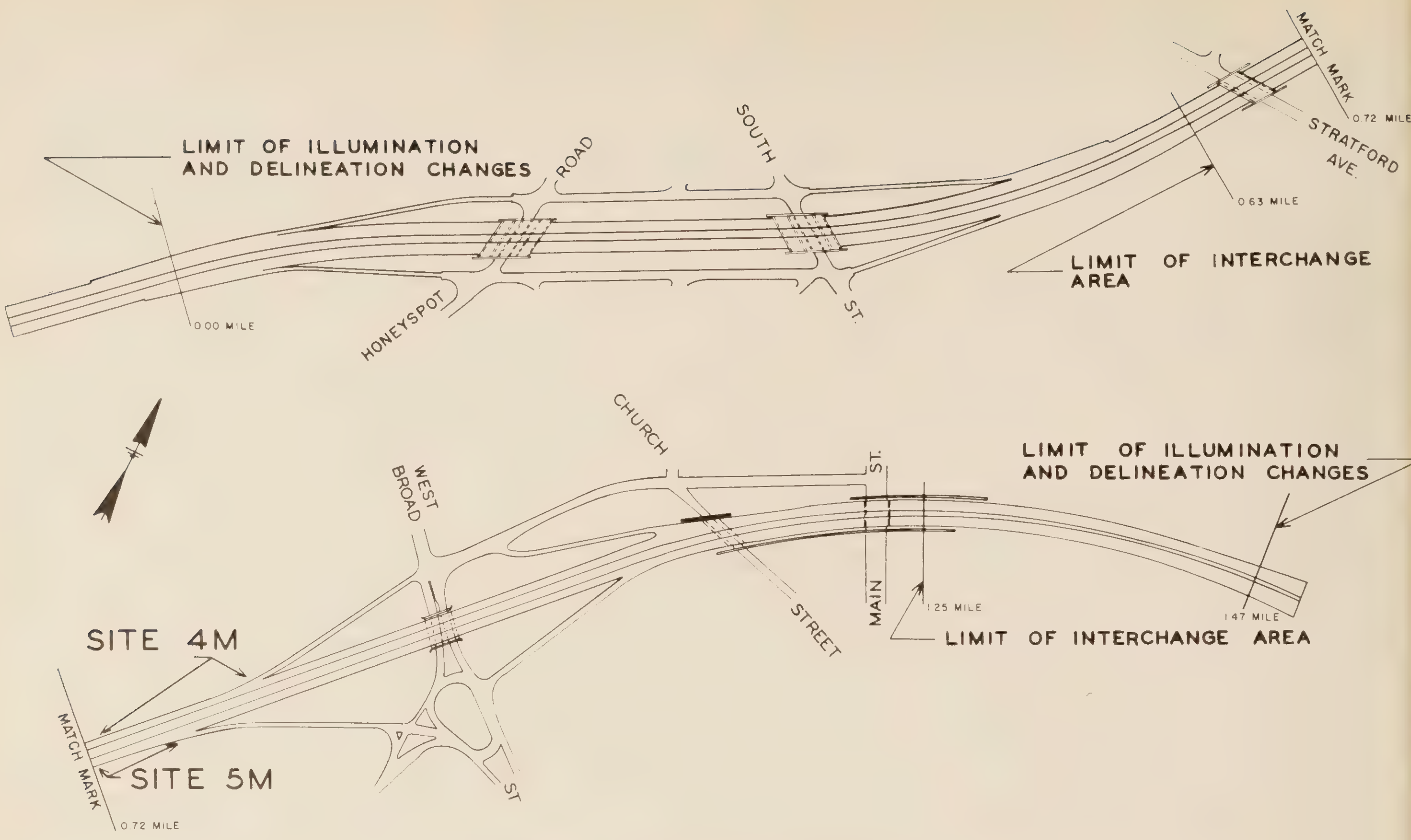


Figure 1.—Plan of general study area.

5M would reveal the most significant effects evidenced by the nine variable conditions of illumination and delineation.

From the New York State line to 8 miles east of New Haven, a distance of 53 miles, the Connecticut Turnpike was illuminated to a level of 0.8 foot-candle on the roadway and access ramps. The exit ramps were illuminated at a somewhat lower level. The roadway consisted of three 12-foot concrete lanes on either side of a median that varied in width from 4 feet to 30 feet.

At the study location, the West Broad Street interchange in the town of Stratford, 15 miles southwest of New Haven, the six lanes were abutted by 2-foot-wide bituminous gutter strips and 10-foot-wide bituminous shoulders. The depressed grass median was 30 feet in width and the access ramp and exit ramp roadways were 13 feet wide. Average daily traffic volumes on the Turnpike just west of the study interchange wer 17,000 vehicles in each direction. At th interchange, almost 7,000 vehicles left th Turnpike and over 7,000 vehicles entered daily.

The general area of the interchange, i which the nine lighting conditions were established for the study, is shown in figure 1 Also shown are the limits of illumination an

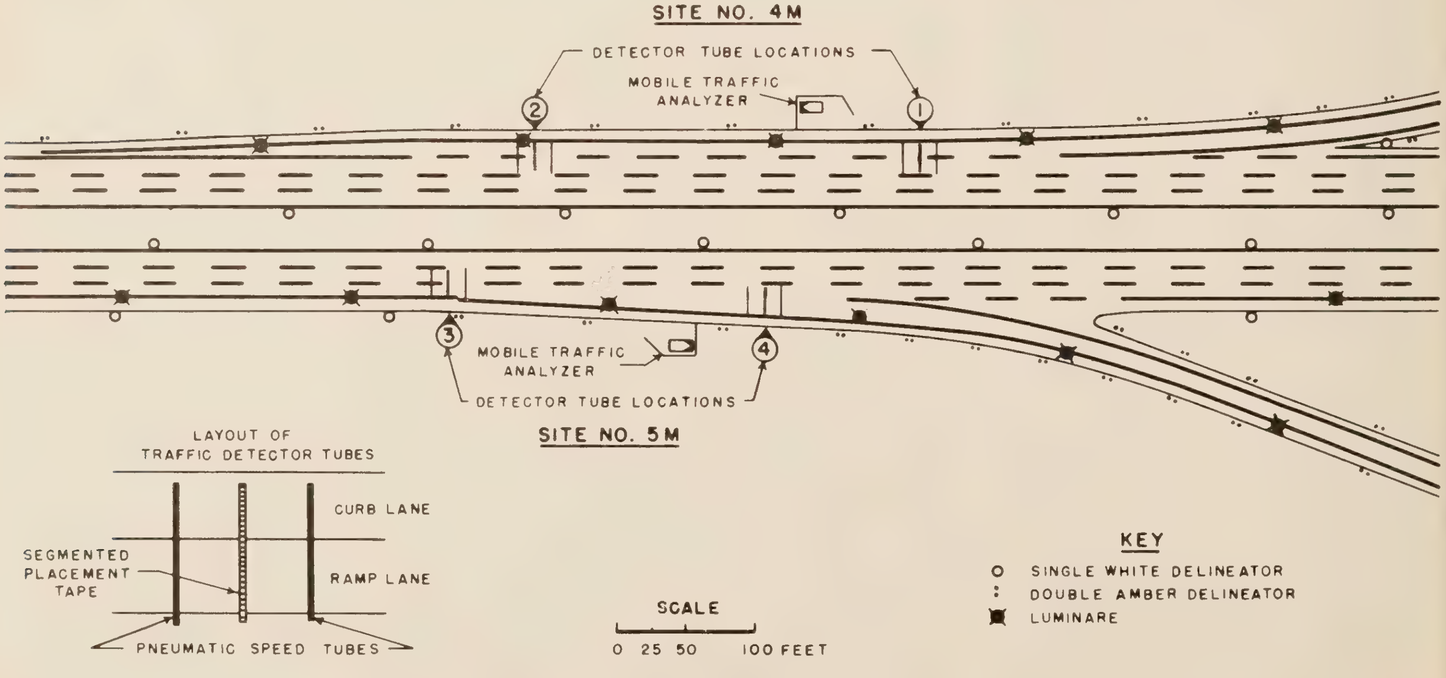


Figure 2.—Plan of specific study locations.

Figure 3.—Access ramp site 4M.

Figure 4.—Exit ramp site 5M.

delineation changes for the eastbound and westbound traffic, and the limits of the interchange area. Lights were controlled within these limits.

Specific observations were made at both the westbound access ramp, site 4M, and the eastbound exit ramp, site 5M. Figure 2 shows the roadway, illumination, delineation, and locations of the recording and detecting equipment in the vicinity of the study sites. Figure 3 shows the access ramp site (4M) looking easterly along the westbound lanes. Figure 4 shows the exit ramp site (5M) looking westerly along on the eastbound lanes.

Partial illumination (for lighting conditions 4, 5, and 6) was attained by changing lamps and ballasts as well as by using specially constructed lamps with the existing ballasts. The actual levels of illumination achieved were determined by the standard practice for measurement as recommended by the Illuminating Engineering Society. The actual values were measured at intervals of 10 feet by the light meter for the study area. For illustrative purposes, however, only typical average foot-candles of illumination are shown in figure 5 for normal illumination and in figure 6 for partial illumination. Generally, the illumination ratio of the average to the minimum was 4 or 6 to 1. The different appearances of the highway under the 2 levels of illumination were readily discernable visually as shown in figure 7.

Field Observations

The mobile traffic analyzer designed and constructed by the Bureau of Public Roads was used in the study to record the traffic data. Constructed from a revamped delivery truck, the traffic analyzer vehicle housed four solenoid-operated adding machines, a digital clock, telegraph keys, and other supporting equipment, shown in figure 8. All of the equipment was electronically interconnected.

The recording units in the vehicle were connected by multiconductor cables to four sets of road-detector tubes placed across the roadway at four specific locations, shown in figure 2. One set of detector tubes was placed across the curb lane and access ramp lane near the beginning (location No. 1) and a second set near the end (location No. 2) of the acceleration lane (site 4M); the third set of detector tubes was placed across the curb and middle lanes near the beginning of the deceleration lane (location No. 3); and the fourth set was placed across the curb lane and exit ramp lane (location No. 4) near the gore area (site 5M). As the motor vehicles on the Turnpike passed over the detector tubes, electronic impulses were transmitted to the traffic analyzer and recorded.

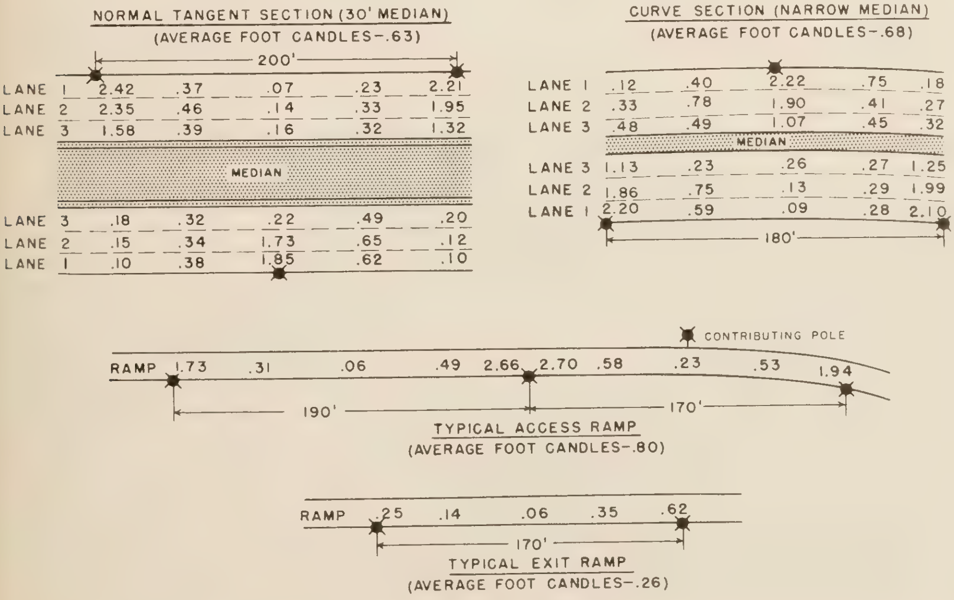


Figure 5.—Measured illumination values under normal illumination.

The data electronically recorded included the speed of the motor vehicle, lateral placement (from which lateral clearances between vehicles were calculated), and time of day to the nearest one ten-thousandth of an hour (from which traffic maneuvers and headway distances were calculated).

A supervisor and four observers were located inside the traffic analyzer vehicle and four more observers were stationed outside, but in the immediate vicinity of the vehicle. The inside observers operated certain keys which recorded vehicle classification and driver action in the merging and diverging traffic areas. The outside observers recorded the manner in which drivers utilized the acceleration and deceleration lanes including various driving actions such as use of brakes, sudden slowdowns, etc. They also recorded traffic volumes and lane changing on those lanes not equipped with road-detector tubes.

Accident data, compiled for both illuminated and nonilluminated areas, were obtained from State Police accident reports. The only Turnpike accidents considered for comparative analyses were accidents which occurred during the first 8 months of 1959. Turnpike accidents prior to 1959 were not considered indicative of the accident experience because the road was only partially open to traffic in 1958. Accident information for the Merritt Parkway and for all other Connecticut State highways, used for comparative purposes, was obtained from the last full year of accident tabulations available from motor vehicle reports.

Analyses and Discussion of Data

The multitude of data recorded could not be treated by normal tabulating procedures and a high-speed electronic computer was employed. For simplicity in analyses of ve-

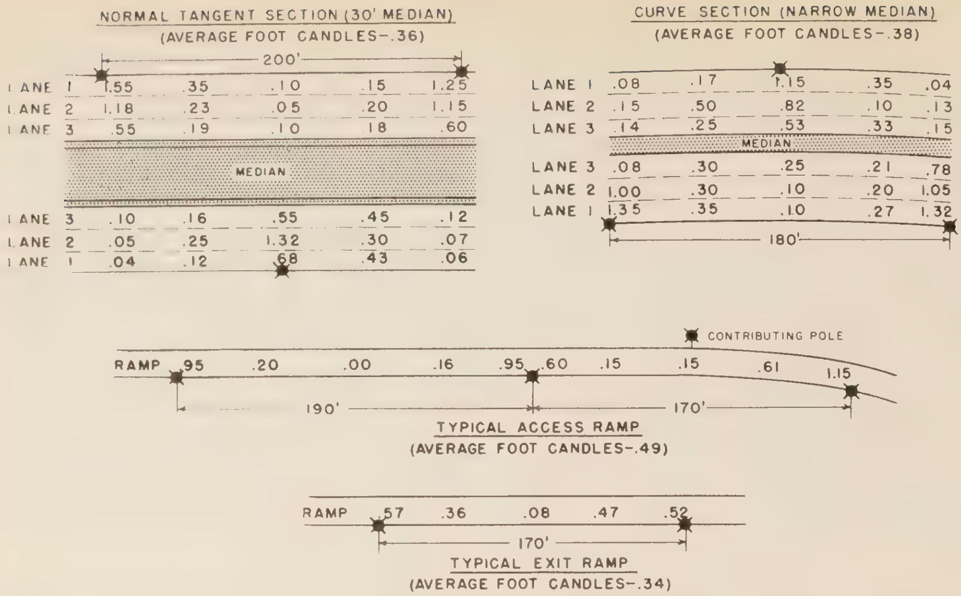


Figure 6.—Measured illumination values under one-half normal illumination.

hicle speeds and lateral placements, motor vehicles were grouped into two categories: (1) light vehicles—consisting of passenger cars and 2-axle, single-tire trucks; and (2) heavy vehicles—consisting of all heavier trucks, combinations, and buses. The vehicles were also classified according to their proximity to other vehicles on the roadway, as follows:

Free-moving vehicle.—One whose longitudinal spacing to the nearest vehicle, ahead or behind and in any lane, was more than 7 seconds.

Adjacent vehicle.—One whose longitudinal spacing to the nearest vehicle in an adjoining lane was 1.4 seconds or less.

Trailing vehicle.—One whose longitudinal spacing to the preceding vehicle in the same lane was 3 seconds or less.

Adjacent and trailing vehicle.—One whose longitudinal spacing was 1.4 seconds or less to the nearest vehicle in an adjoining lane, and at the same time less than 3 seconds behind a preceding vehicle in the same lane.

Other.—One whose longitudinal spacing to another vehicle in the same lane was over 3 but less than 7 seconds; or whose longitudinal spacing to another vehicle in an adjoining lane was more than 1.4 but less than 7 seconds.

The vehicle position classifications thus include free-moving and unaffected; adjacent to a vehicle in the next lane; trailing another vehicle and either adjacent to another vehicle or laterally in the clear; and finally, "other," representing a position of near but not close proximity to other vehicles.

Traffic volumes

The total traffic and the traffic distribution by lanes are shown in table 1. With the exception of one period during nighttime traffic at site 4M (lighting condition No. 8, lane and edge lines and normal illumination), the access and exit ramps carried more traffic than any other lane. Generally the median lane carried the smallest percentage of vehicles and the curb lane the next smallest.

At both sites the percentage of heavy trucks and buses was greater at night than during the day, as shown in table 2. Heavy trucks and buses accounted for 12 percent of the vehicles recorded at site 4M and 10 percent recorded at site 5M. The smaller percentage of heavy vehicles recorded at site 5M was due to the location of a toll plaza east of the study site and the preceding exit ramp west of the study site which led directly to U.S. Route 1 in Stratford. From an analysis of traffic data (not shown in tables) it was found that a higher percentage of heavy vehicles were in the through-traffic streams.

Vehicle speeds

No significant relation between vehicle speeds and the lighting conditions was established by the study. Variations among daytime speeds were as great or greater than between day and night vehicle speeds; and these variations were found for free moving, adjacent, and trailing light and heavy vehicles. A summary of the average day and night speeds recorded at the four locations is given in table 3.

Classified by the nine lighting conditions during day and night traffic, the difference between the average speeds rarely exceeded 3 miles per hour, and generally the difference was less than 1 mile per hour. A representative comparison of the speeds of light vehicles on through traffic lanes, their lateral placements, and the clearances between adjacent vehicles, is shown in table 4. Cars and light trucks observed in the curb lane at site 4M and in the middle lane at site 5M were used for the comparison because these lanes carried the greatest proportion of through vehicles.

A review of the distribution of all speeds (of which table 4 is but a representative sample) indicated that the percentage of through light vehicles traveling below 40 miles per hour could provide an index for comparing the relative advantages of the study lighting conditions. The index derived for each lighting condition was the variation (expressed in percent) of the percentage of nighttime vehicles traveling below 40 miles per hour from the percentage of the total daytime vehicles observed at the same site traveling below 40 miles per hour during the average day. For example, if 35 percent of the cars and light trucks traveled below 40 miles per hour during the average day and 30 percent traveled below 40 miles per hour at night, the percent variation was $(30-35) \div 35$ or 14 percent. If the nighttime percentage of vehicles traveling below 40 miles per hour was lower than the daytime figure, then the variation was minus. If the converse were true, the variation would be plus.

Figure 7.—A section of the Connecticut Turnpike under one-half normal illumination (left) and normal illumination (right).

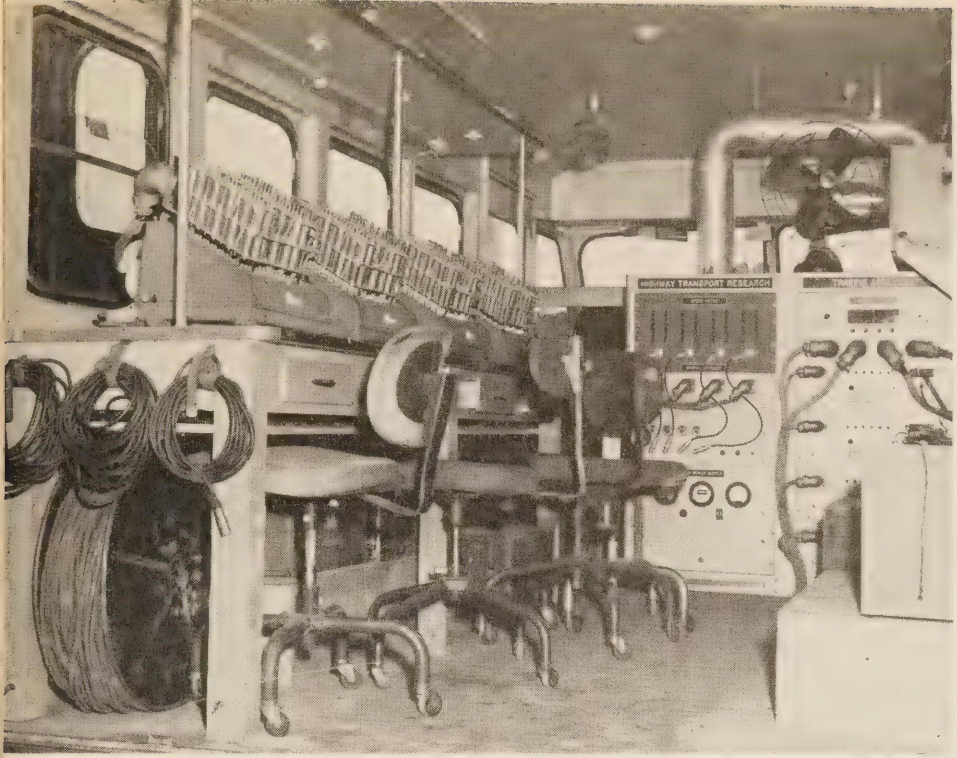


Figure 8.—Interior view of the mobile traffic analyzer vehicle.

In simpler words, a minus variation means at a larger proportion of vehicles were aveling faster at night than in daytime.

The seemingly large values that appear for me lighting conditions, shown in figures 9 nd 10, resulted usually from the fact that uring the daytime the average percentage of bserved speeds below 40 miles per hour was uite low. For site 4M, the least percentage ariation occurred for the lighting conditions full illumination with and without delineation (condition Nos. 8 and 9), partial illumination with delineation (condition No. 5), and delineation but no illumination (condition No. 3). From the variations it would appear that roadside delineation exhibited an influence toward maintaining minimum speed differentials; and that where delineations were present, partial illumination exhibited very little improvement over no illumination.

The data for site 5M, shown in figure 10, revealed an entirely different trend. (The great difference in vertical scale between figures 9 and 10 should be noted.) A smaller percentage of through light vehicles traveled below 40 miles per hour during night traffic than during the day for all lighting conditions except condition No. 4, edge and lane lines and one-half normal illumination. One explanation given for the exception was that the reduced illumination in the area of heavy diverging maneuvers resulted in a loss of confidence and subsequent lowering of speed.

To test the results given in figures 9 and 10, cumulative speed curves for each lighting condition were compared to the similar curve for the average day at the two study sites. The findings of the comparison lent support to the effects of lighting determined by speed variations.

Lateral placement

Analyses of the data recorded for lateral placement of vehicles failed to reveal any significant differences for the nine lighting conditions. Certain trends were indicated by the analyses of average day versus night placements, as shown in figures 11 and 12, but none that could be used as criteria for evaluation of the lighting conditions.

In this study, the lateral placement of a vehicle was the distance from the center of the vehicle to the right edge of the traffic lane. In figure 11, for light vehicles, the average placement, averaged for all lighting conditions, showed that at the start of the exit ramp and near the end of the access ramp there was considerable difference between the placements in the outer lane and the inner lane for both day and night traffic. This difference, however, did not appear to exist in the average placement of heavy vehicles (fig. 12).

Analysis of the placement data did indicate that all vehicles in the ramp lanes at both sites

Table 1.—Distribution of traffic by lanes under different highway lighting conditions

Highway lighting condition number and code [1]	Daytime traffic					Nighttime traffic				
	Vehicles per hour	Percent of vehicles using—				Vehicles per hour	Percent of vehicles using—			
		Ramp lane	Curb lane	Middle lane	Median lane		Ramp lane	Curb lane	Middle lane	Median lane
Site 4M:										
No illumination:										
1.—LL [2]	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
2.—L-EL	672	51.0	22.6	21.3	5.1	313	48.4	29.5	18.4	3.7
3.—L-EL,D	1,236	36.8	17.8	34.0	11.4	491	35.6	27.7	29.8	6.9
Partial illumination:										
4.—L-EL,½I	1,219	42.4	19.1	27.6	10.9	519	35.2	23.1	27.0	14.7
5.—L-EL,D,½I	1,174	38.7	17.1	34.7	9.5	580	40.0	20.8	31.6	7.6
6.—L-EL,D,½I(int.)	1,264	40.6	19.2	30.8	9.4	553	37.0	21.7	34.4	6.9
Full illumination:										
7.—L-EL,D,I(int.)	1,096	40.5	20.0	30.3	9.2	533	38.5	23.1	30.4	8.0
8.—L-EL,I	798	52.0	21.6	21.2	5.2	376	28.5	47.0	20.0	4.5
9.—L-EL,D,I	1,296	39.8	19.0	31.1	10.1	576	40.3	22.0	30.9	6.8
Average	1,094	42.7	19.6	28.9	8.8	494	37.9	26.9	27.8	7.4
Site 5M:										
No illumination:										
1.—LL [2]	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
2.—L-EL	629	38.8	17.2	32.6	11.4	420	48.9	21.4	24.5	5.2
3.—L-EL,D	1,503	47.2	10.7	26.0	16.1	666	44.2	20.8	27.9	7.1
Partial illumination:										
4.—L-EL,½I	1,509	51.2	10.6	22.8	15.4	570	45.1	19.8	24.5	10.6
5.—L-EL,D,½I	1,488	48.6	10.7	24.5	16.2	656	49.2	14.8	26.9	9.1
6.—L-EL,D,½I(int.)	1,478	48.4	11.7	25.4	14.5	563	47.0	22.0	24.4	6.6
Full illumination:										
7.—L-EL,D,I(int.)	1,567	48.4	10.8	25.5	15.3	582	43.8	22.0	27.2	7.0
8.—L-EL,I	1,401	46.5	10.7	27.1	15.7	810	59.8	18.4	17.5	4.3
9.—L-EL,D,I	1,443	47.7	10.8	25.6	15.9	588	48.5	17.8	27.2	6.5
Average	1,377	47.1	11.6	26.2	15.1	607	48.3	19.6	25.0	7.1

[1] Code: LL—lane lines only; L-EL—lane and edge lines; D—roadside delineation; ½I—one-half normal highway illumination; (int.)—interchange area only; I—normal highway illumination. [2] Traffic data were not available.

Table 2.—Percent of heavy vehicles recorded at the study sites, classified by lighting condition

Highway lighting condition number and code [1]	Percent of total traffic volumes			
	Site 4M		Site 5M	
	Day	Night	Day	Night
No illumination:				
1.—LL	22	23	12	17
2.—L-EL	16	17	10	13
3.—L-EL, D	10	15	7	12
Partial illumination:				
4.—L-EL, ½I	11	15	7	13
5.—L-EL, D, ½I	16	13	9	10
6.—L-EL, D, ½I (int.)	11	11	9	13
Full illumination:				
7.—L-EL, D, I (int.)	11	11	5	8
8.—L-EL, I	14	12	10	15
9.—L-EL, D, I	9	12	8	8
Average	12	13	9	12

[1] For lighting code, see table 1, footnote 1.

Table 3.—Summary of average day and night speeds under all lighting conditions recorded at the four locations

Location	Light vehicles		Heavy vehicles	
	Daytime speed	Nighttime speed	Daytime speed	Nighttime speed
Site 4M:				
Location No. 1:	*m.p.h.*	*m.p.h.*	*m.p.h.*	*m.p.h.*
Ramp lane	38.9	38.8	31.4	29.1
Curb lane	50.0	49.2	48.4	47.7
Location No. 2:				
Ramp lane	41.0	40.3	34.0	30.8
Curb lane	47.7	46.2	47.3	46.4
Site 5M:				
Location No. 3:				
Curb lane	42.3	42.8	45.5	47.3
Middle lane	57.6	57.4	55.9	56.4
Location No. 4:				
Ramp lane	37.1	38.1	37.1	39.4
Curb lane	48.5	49.4	49.5	53.1

tended to travel closer to the through lanes at night; and that all vehicles in the curb lane at both sites generally traveled closer to the right edge of the traffic lane at night.

Headway distance

It was believed that the position a driver selected for his vehicle, in relation to the preceding vehicle in the same traffic lane, would be influenced by various lighting conditions and thereby would afford the researchers an opportunity to measure driver behavior under each lighting condition. The approximate time equivalent of the recommended safe distance between successive vehicles at the posted speed of 60 miles per hour is 1.4 seconds. The percentage of headways below this longitudinal time spacing was therefore selected as the criterion in evaluating the effect of lighting conditions. However, a review of the percentage distributions could not establish any definite relation between lighting effects and headway.

Clearances between vehicles

As utilized in this study, clearance relates to the lateral distance in feet between bodies of adjacent vehicles. The clearances of through light vehicles, shown in table 4, were generally representative of all vehicles under all lighting conditions. Clearance appeared to be greater at site 5M than at site 4M under all but one of the lighting conditions. T
differences in measurement recorded at ea
site, however, were quite small in magnitu
and so varied among the lighting conditio
that no distribution significance could
realized.

Lane usage

The most significant findings of the stu
related to the use of the acceleration a
deceleration lanes. Data for this phase
the analyses were obtained by the observe
stationed outside the mobile traffic-analyz
vehicle. These observers recorded the numb
of vehicles utilizing the access ramp and t
proportion of the length of the accelerati
lane which was traversed by each vehi
before crossing into the curb lane. At t
exit site, vehicles using the deceleration la
and the length of use, were also recorded.

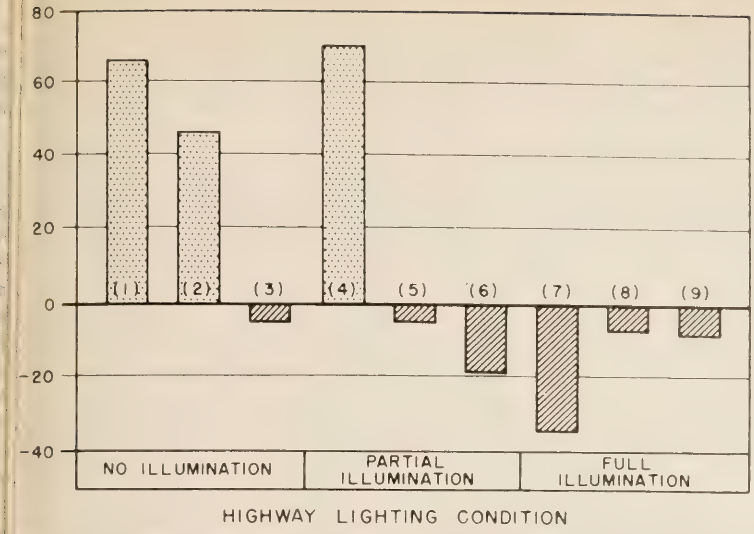
For ease and accuracy in recording observ
data, the acceleration and deceleration la
were divided into three equal sections. T
percentage of total vehicles crossing into a
out of each third of the lane under each lighti
condition at night was paired with the co
parable percentage figure for the average da
The difference between the figures was th
expressed as a percentage of the average d
figure, and the percentages for the three s
tions of the speed-change lanes were average
The averages of the 3 percentage variatio
from the average day are plotted in figures
and 14 for each lighting condition. No p
centage variation is given for condition No.
as no data for "lane lines only" was availab
The average variation is in effect a measure
how close night operation approaches dayti
operation.

For site 4M, figure 13, it was found th
under the same conditions of delineation,
of the acceleration lane at night was direc
related to the level of illumination. As t
amount of illumination increased, night usa
of the acceleration lane more nearly a
proached daytime usage. For example, wi
delineation and no illumination, condition N
3, night usage of the acceleration lane was
percent different from the average day; wi
one-half illumination, condition No. 5, t
variation dropped to 23 percent; and with f
illumination, condition No. 9, the variati
was 17 percent.

Table 4.—Summary of average speed, lateral placement, and clearance for light vehicles in through traffic lanes

Highway lighting condition number and code [1]	Site 4M						Site 5M					
	Speed		Placement [2]		Clearance [3]		Speed		Placement [2]		Clearance [3]	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
	m.p.h.	*m.p.h.*	*Feet*	*Feet*	*Feet*	*Feet*	*m.p.h.*	*m.p.h.*	*Feet*	*Feet*	*Feet*	*Feet*
No illumination:												
1.—LL	49.8	47.0	6.6	6.1	6.9	6.2	55.9	57.2	6.4	6.0	8.6	8.0
2.—L-EL	51.3	48.1	6.7	6.8	7.4	6.8	56.8	56.5	6.7	6.5	8.0	7.3
3.—L-EL, D	49.2	47.2	6.7	6.4	7.4	7.0	58.5	57.7	6.8	7.2	8.3	8.3
Partial illumination:												
4.—L-EL, ½I	50.3	51.2	6.9	6.4	7.4	6.2	57.5	58.4	6.8	6.9	8.4	8.0
5.—L-EL, D, ½I	50.8	50.0	6.5	6.5	7.1	7.8	56.9	55.5	6.6	6.7	8.1	8.5
6.—L-EL, D, ½I (int.)	49.8	50.5	6.6	6.6	7.2	6.8	57.4	56.7	6.8	6.6	8.1	7.9
Full illumination:												
7.—L-EL, D, I (int.)	48.8	49.7	6.5	6.6	7.1	7.6	58.9	58.3	7.1	6.7	8.4	8.2
8.—L-EL, I	51.0	49.0	6.9	6.5	8.3	7.6	59.1	58.5	6.9	6.9	8.2	8.4
9.—L-EL, D, I	49.5	49.8	6.7	7.0	7.6	7.3	57.8	57.5	7.2	6.8	8.4	7.9
Average	50.0	49.2	6.7	6.5	7.4	7.0	57.6	57.4	6.8	6.7	8.3	8.1

[1] For lighting code, see table 1, footnote 1. [2] Distance in feet center of car to right edge of lane. [3] Clearance in feet between bodies of adjacent cars.



igure 9.—Night from average day percentage variations of speeds for through light vehicles traveling below 40 miles per hour under the nine lighting conditions at site 4M.

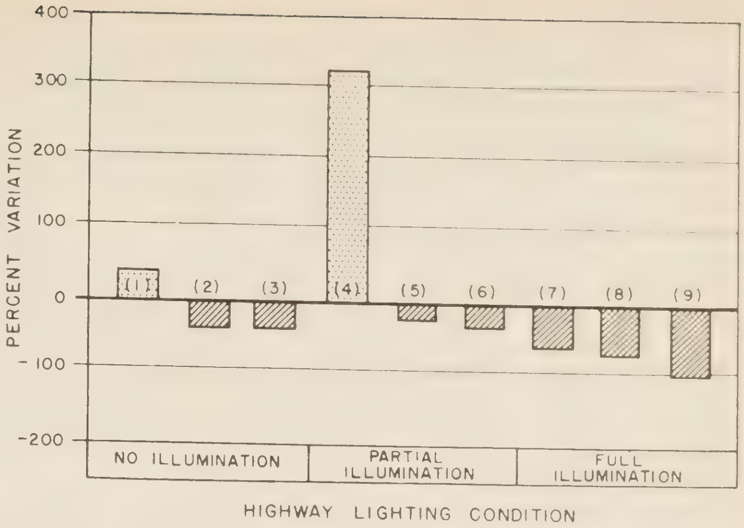


Figure 10.—Night from average day percentage variations of speeds for through light vehicles traveling below 40 miles per hour under the nine lighting conditions at site 5M.

In the use of the deceleration lane at site M, figure 14, full illumination also yielded he best results. One-half illumination, on he average, produced slightly larger variations om daytime operations than no illumination. Again the importance of delineation was emonstrated. Under full illumination with elineation, the percentage variation was aliost negligible, whereas under full illuminaon with no delineation the variation was ver 15 percent.

Other driver behavior recorded included se of brakes, sudden deceleration, cutting ver, and changing lanes. Analyses of the bserved data revealed nothing of significance. here was more sudden deceleration and use of rakes at the exit ramp site for condition No. , lane and edge lines only, than under the ther lighting conditions during hours of arkness. During daylight hours, there was n even higher total of such driver behavior t both study sites.

ccident data analyzed

Correlation of traffic operations with accients was found to be rather inconclusive beause of the limitations of the data available. Traffic volumes and other highway characteristics were different for the illuminated and nonilluminated sections of the Connecticut Turnpike. Incomplete roadway openings, general construction cleanup, etc., made it necessary to limit the surveillance of Turnpike accidents to the first 8 months of 1959.

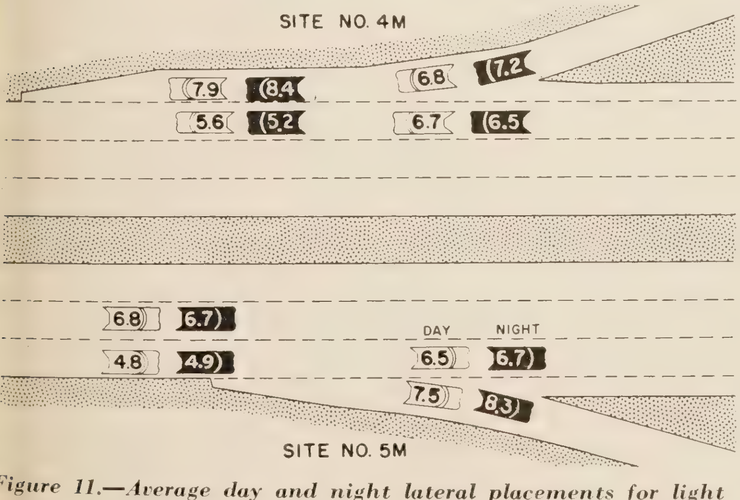
A summary of the general accident statistics for the illuminated and nonilluminated sections of the Turnpike is shown in table 5 along with similar data for the nonilluminated Merritt Parkway and all State highways.

The accident rates for both day and night travel on the Turnpike were considerably lower than on either the Merritt Parkway or the State highways. This was to be expected because of the higher standards of design of this modern controlled-access facility and its traffic appurtenances.

Analyses of the accident rates on the Turnpike revealed a slightly higher rate for the illuminated section during the day than for the nonilluminated section, and an appreciable higher rate for the illuminated section during the nighttime. Comparing day and night accident rates on the illuminated section, the night rate was 1.76 times that of the day rate; while on the nonilluminated section, the night rate was 1.36 times the day rate. However, testing the differences statistically, the accident rates did not prove to be significant. Also, when evaluated with respect to the wide variation in volumes and other characteristics between the illuminated and nonilluminated sections, the differences between the accident rates did not appear to be significant.

Analyses were also made of the relative exposure to accidents. This basically involved a comparison of the traffic volumes, frequency of ramp intersections, and general roadway features. While it appeared that conditions in the illuminated section were considerably more conducive to accidents than in the nonilluminated section, the following distinctions were made:

- The general roadway design standards in the two sections were the same for maximum curvature, maximum gradient, and ramp intersections.
- The average daily traffic volume on the illuminated section was approximately 3.6 times that on the nonilluminated section.



igure 11.—Average day and night lateral placements for light vehicles, averaged for all lighting conditions. Distance in feet from center of vehicle to right edge of traffic lane.

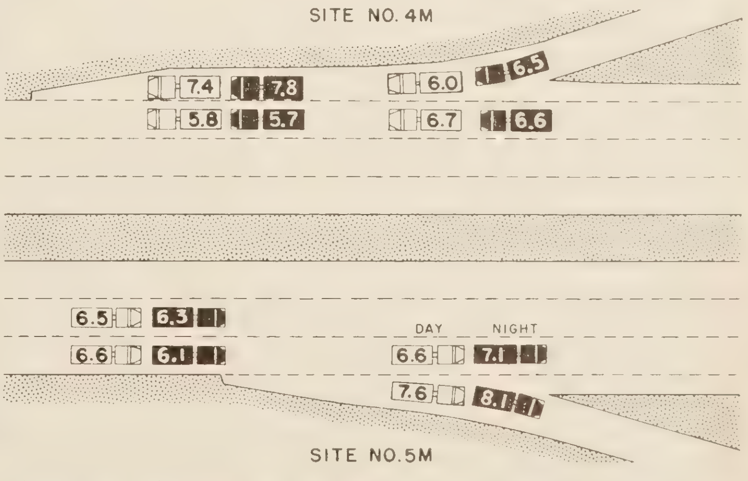


Figure 12.—Average day and night lateral placements for heavy vehicles, averaged for all lighting conditions. Distance in feet from center of vehicle to right edge of traffic lane.

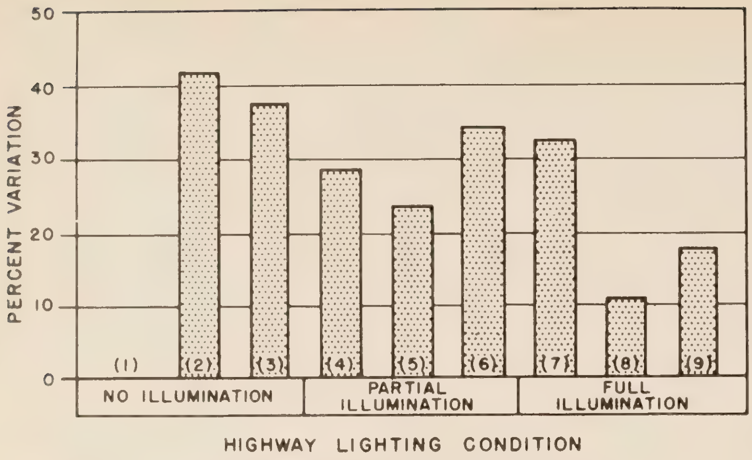


Figure 13.—Night from average day percentage variations of use of acceleration lane at site 4M. (No data available for condition No. 1.)

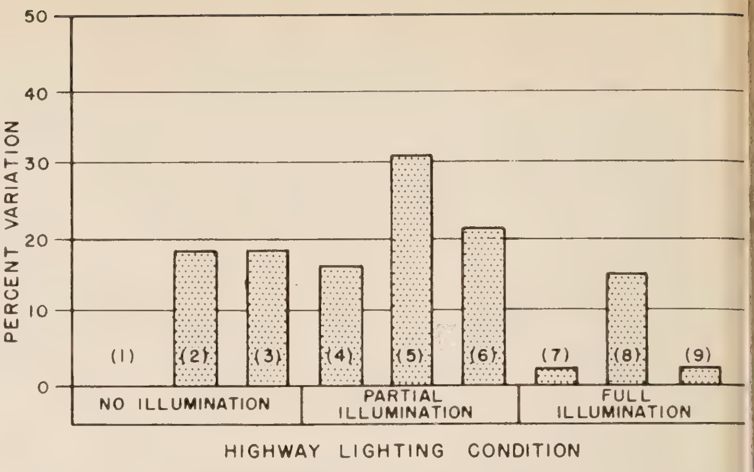


Figure 14.—Night from average day percentage variations of use o deceleration lane at site 5M. (No data available for conditio No. 1.)

- There were twice as many ramp intersections per mile along the Turnpike in the illuminated section.
- The illuminated section followed a more undulating course than the nonilluminated section.

The importance of these highway and traffic features was evidenced by the fact that within the illuminated section, 43 percent of the accidents occurred in only 27 percent (14.3 miles) of the total 53 miles. The average daily traffic volumes in the 14.3-mile section ranged from 30,000 to 40,000. A portion of the 14.3-mile section, the 6.9 miles with the highest traffic volume, which was about 1.6 times that for the total 53 miles, was also subjected to a comprehensive examination. The comparative results are shown in table 6.

Several significant facts were evident from the accident summary. The daytime accident rate of the 6.9-mile section was 114 per 100 million vehicle-miles, or 1.54 times the daytime rate (74) for the entire 53 miles of illuminated highway. The nighttime accident rate of the 6.9-mile section was 135 per 100 million vehicle miles, or 1.18 times that of the daytime rate and only 1.04 times the average nighttime rate for the 53-mile section.

The daytime accident rate increased with the traffic volumes whereas the nighttime rate remained substantially the same and was then only slightly greater than the daytime rate on the same section. It must be realized that in the areas under discussion the traffic volumes during the day were about double those during the night.

It would appear from the analyses of accident rates for the illuminated sections of varying traffic volumes that highway illumination may have had a beneficial effect on accident experience. However, it was evident that the value of accident experience in establishing criteria for highway illumination would require considerably more dat than was available, if statistically significan results were to be obtained.

Table 5.—Summary of accident data for the Connecticut Turnpike, Merritt Parkway, and other Connecticut State highways

Facility	Highway mileage	Total travel, vehicle-miles		Number of accidents		Accident rate[1]		
		Day	Night	Day	Night	Day	Night	Ratio: night/day
		100 million	*100 million*					
Connecticut Turnpike:[2]								
Illuminated	53.0	2.40	1.29	177	168	74	130	1.76
Non-illuminated	75.7	.99	.53	71	52	72	98	1.36
Total	128.7	3.39	1.82	248	220	73	121	1.66
Merritt Parkway—1957	37.5	3.45	.97	493	402	143	414	2.90
All State highways—1957	3,224.7	39.07	16.75	8,736	6,117	224	365	1.63

[1] Number of accidents per 100 million vehicle-miles. [2] Accident data from Jan. 1, 1959, to Sept. 1, 1959.

Table 6.—Accident summary of the high traffic volume areas in the illuminated section of the Connecticut Turnpike

Highest traffic volume sections	Total travel, vehicle-miles		Number of accidents		Accident rate[1]	
	Day	Night	Day	Night	Day	Night
	100 million	*100 million*				
6.9-mile section	0.44	0.23	50	31	114	135
14.3-mile section	.85	.45	80	70	94	156
Total illuminated length (53 miles)	2.40	1.29	177	168	74	130

[1] Number of accidents per 100 million vehicle-miles.

Summary

The results of the analyses of the stud data presumably can be considered typica for a freeway similar in design and traffi volumes to that of the Connecticut Turnpike The interchange studied was probably als typical of freeway interchanges both fron the standpoint of geometrics and traffi volumes. Under congested traffic conditions the results might differ considerably.

The more important results evolved fron the study are as follows:

1. Neither average speed, lateral placement headway distance, nor lateral clearanc showed any consistent change between da and night conditions by virtue of highwa illumination or delineation.

2. Nighttime usage of the acceleration lan approached daytime usage as the level o illumination increased. A similar patter existed at the deceleration lane, although i was more variable.

3. In general, it appears that beneficia results of illumination in the deceleratio area were derived when it was used at the fu level and that even greater services wer derived when illumination was combined wit roadside delineation. Illumination of th interchange area only did not appear to b desirable insofar as the access ramp site wa concerned.

4. Analyses of the accident data for th illuminated and nonilluminated sections c the Connecticut Turnpike do not provid conclusive results because of the extrem variance in traffic volumes and other highwa characteristics.

Despite the extensive analyses of th tremendous volume of data recorded, n positive or significant trends could be deve oped that would define specific warran for highway lighting. However, the resul of the investigation did point up the valu

(Continued on page 71)

Digital Recording for Highway Research

Y THE DIVISION OF TRAFFIC OPERATIONS
UREAU OF PUBLIC ROADS

Reported [1] by RICHARD C. HOPKINS,
Chief, Instrumentation Branch

HE moving finger of Omar Khayyam possibly could have been inspired by the atrivance of some 12th century scientist io attached a stylus to a lever transducer that an ancient analogue was produced on lay or wax tablet drawn through this device a slave walking in cadance with a water ck. The discoveries of magnetism and ctricity did not produce any changes in this sic system; they only brought operational provements such as pen motors and galnometers, capillary pens and light beams, ing clocks and synchronous motors, and per charts to replace the limited clay tablet.

Since the inception of the oscillograph, ousands and thousands of miles of analogue arts have been recorded, analyzed, tranibed, and filed. And the analogue chart, ich may be described as a pictoral represenion of a fact, will certainly always be with but, its future use will become more and ore confined to special and carefully selected plications. Taking the place of the anague, digital recording (recording information numbers) is becoming more commonly ed and appreciated by the research engineer.

Automatic digital recording was possible d could have been in common use several rs ago. However, the data-reduction proces were limited to the use of desk calculatg machines or punched card machines, and was relatively easy for clerks to supply its from analogues as fast as calculatingchine operators or key punch operators uld handle them.

Only a few short years ago, the digital nputer, in the evolution of electronics, was anged from a million-dollar wonder to ew-thousand-dollar office machine. Users on became aware of the machine's tremenlus capacity for digits. It was able to ingest d digest digits faster than small armies of th century clerks could analyze, transcribe, d key-punch analogue charts.

The obvious answer to the problem of the e computer was to eliminate the analogue d to record all information intended for tomatic data reduction in digital form. So, lizing the circuits and techniques that had en developed for the digital computer, ctronic instrument manufacturers have de available "hardware" and complete its which will deliver digital records from sting analogue systems in addition to perming in their primary application in newly signed digital systems.

Glossary of Terms

Some of the electronic terms employed in this article are as follows:

Print command.—An electrical signal which indicates to a digital recorder that the periodic data collection is complete and is to be printed. This signal may be either manually or automatically controlled.

Staircase.—A digital code in which each digit from 0 to 9 is represented by a discrete voltage that is one of equal sequential steps above or below a design reference voltage.

10-Line.—A digital code in which each digit from 0 to 9 is represented by an individual electrical contact.

Binary code.—A term referring to one of several electrical methods of indicating a decimal number in a binary system. The two most frequently used systems in digital recording totalize binary indications of 1–2–4–8 or 1–2–2–4 to obtain the desired digit.

Time base generator.—An electronic device which provides a repetitive signal of known frequency at a high degree of accuracy. (See digital clock.)

Digital clock.—An electronic device which accepts the output of a time base generator, accumulates totals of usable time intervals, and provides for the time increment recording in a digital system.

Electronic decade scaler.—A binary device which counts electrical input signals and provides a digital output of the total between 0 and 9. The device then produces a "carry-over" signal and repeats its counting sequence.

Digital voltmeter.—An electronic instrument which can accept direct current voltages and display the values as decimal numbers. The voltmeter also provides for a recorder input by one of the standard digital codes.

Digital Recording Systems

The purpose of this article is to introduce those familiar with analogue recording techniques to some of the standard electronic units which may be combined to form flexible digital recording systems.

The Bureau of Public Roads has been digitally recording traffic survey data since 1946 when special solenoids were mounted on standard adding machines due to the lack of commercially available equipment. Ten years later it was still necessary for the Bureau of Public Roads to provide its own solenoids. Today, however, the manufacturers of business machines provide for remote electrical actuation of nearly all models and almost all manufacturers either provide for a direct output to a motorized tape punch or have an auxiliary unit to provide this output. This rapid trend toward the remote or automatic handling of data by office machines is only mildly indicative of the advances being made in electronic computer print-outs or recorders designed for digital systems.

These newer recorders will be briefly discussed and a few typical systems will be shown that can be used individually or in combination to produce direct printed records of measures of physical quantities.

It is difficult to observe any digital system without becoming fascinated by the rapidity and positiveness with which the data are printed and to admire the complex mechanism which so faithfully transfers electrical intelligence into numerals. In fact, the effect is to often overweight the importance of the recorder which may mask a much more complicated system of data collection. So,

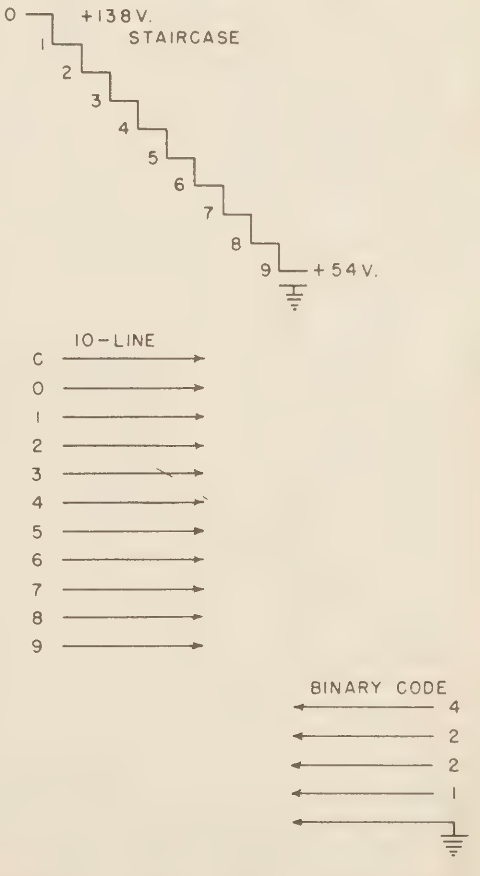


Figure 1.—Three digital recorder input codes.

This article was presented at the 39th Annual Meeting ohe Highway Research Board, Washington, D.C., January 1).

because of the straightforward design of these recorders, it is possible for the purpose of this article to consider only a few external features that are pertinent to any digital system and then consider in more detail such systems and possible alternates.

Selection of the first digital recorder will probably be dictated by the output of the system that has determined its need. Therefore, since the features of accepting and storing digits to be printed on command are common to all recorders, it is only necessary to refer to recorders in terms of *staircase, 10-line,* or *binary code.* These digital recorder input codes are illustrated in figure 1.

In a *staircase* input each digit in each column is represented by some particular voltage with respect to a zero level. A typical example is the use of +138V to represent "0," +54V to represent "9," and the other digits represented by voltages equally separated between these two.

The *10-line* recorder provides a common terminal for a battery connection and 10 digit terminals for each column. A digit is stored in such a recorder by simply completing the circuit from the other terminal of the battery to the proper digit terminal.

A *binary code* input is what the name implies. In this system, the sum of the code units is the decimal equivalent of the binary number produced by the electronic system. Because of electronic expediency, code values of 1–2–2–4 are usual although recorders with a 1–2–4–8 input are available.

In physical dimension, a digital recorder is about 20 inches long, 12 inches high and 15 inches deep and may be obtained in an individual cabinet or with a panel for relay rack mounting. The recorder normally operates from 120V 60-cycle power with a demand of the order of 150 watts. Recorder models are available to print from 6 to 12 digits as rapidly as 5 times per second with some special computer print-outs capable of much higher recording rates.

Time recording

In considering the systems that collect and prepare the data to be recorded, the measurement of time, being the abscissa of almost all of the common analogue records, should probably be considered first. Unit time in the analogue is unit length and its measure is dramatically illustrated by the bulk of the recorded chart.

In a digital system, time, like all other quantities, must be recorded in its numerical value. An exception to this would be a situation which permitted the recorder print command to be controlled by time units. Each record would then indicate the passage of one time unit and elapsed time could be determined in the data reduction process by totaling the individual recordings.

In the general case, however, a time base generator or digital clock must be included as a part of the data collection system and its significant figures recorded. Two typical time bases are shown in figure 2. A quartz crystal oscillator (usually 100 kc.) is connected to suitable electronic frequency divider circuits to produce the time unit required. These time units are counted by an electronic decade scaler with an output for each count of 10 carried over to another similar scaler. As many decade scalers as necessary may be interconnected and the output (staircase or binary code) of each scaler is always available for transfer to a proper digital recorder.

A second practical, and somewhat more mechanical, system would utilize a synchronous motor, proper reduction gears, and an electrical contact closed by the driven cam. Ten contact, spring-driven stepping switches would then be used in each decade and a 10-line output to a digital recorder would be available.

As circumstances might require, the stepping switches could be actuated by the quartz crystal oscillator and divider circuits or the electronic decade scalers could count the contact point closures. Other suitable time base circuits make use of capacitor dischar time, tuning forks, direct counting of t powerline frequency, etc.

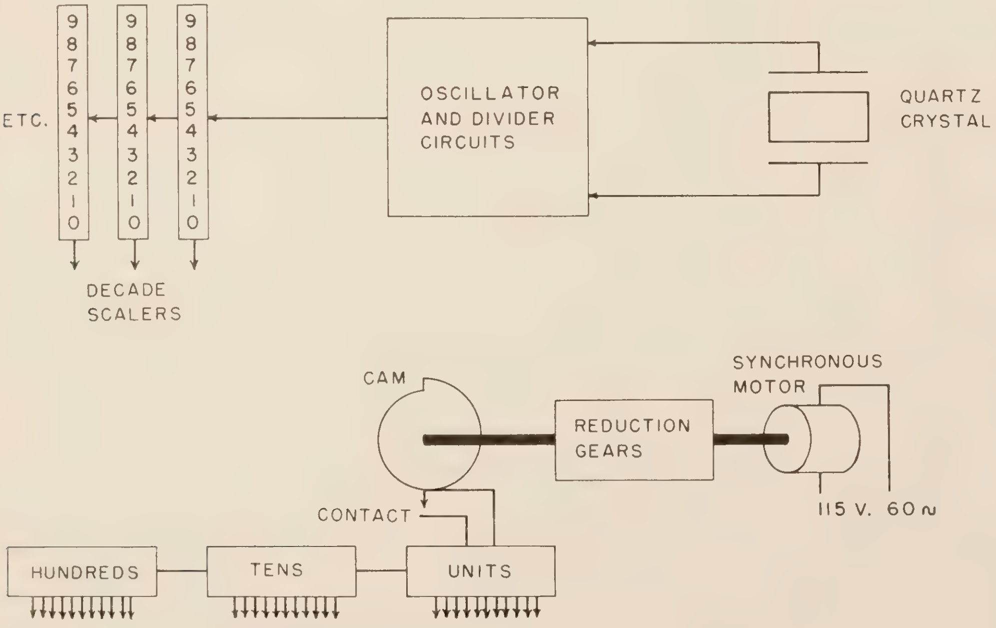


Figure 2.—Typical digital clocks for time recording.

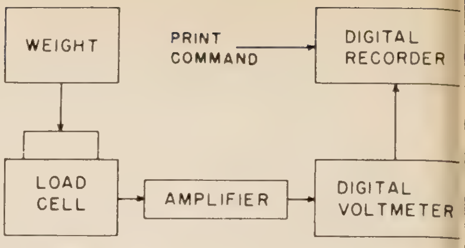


Figure 3.—A direct method of convertin weight analogue systems to digital r cording.

Weight recording

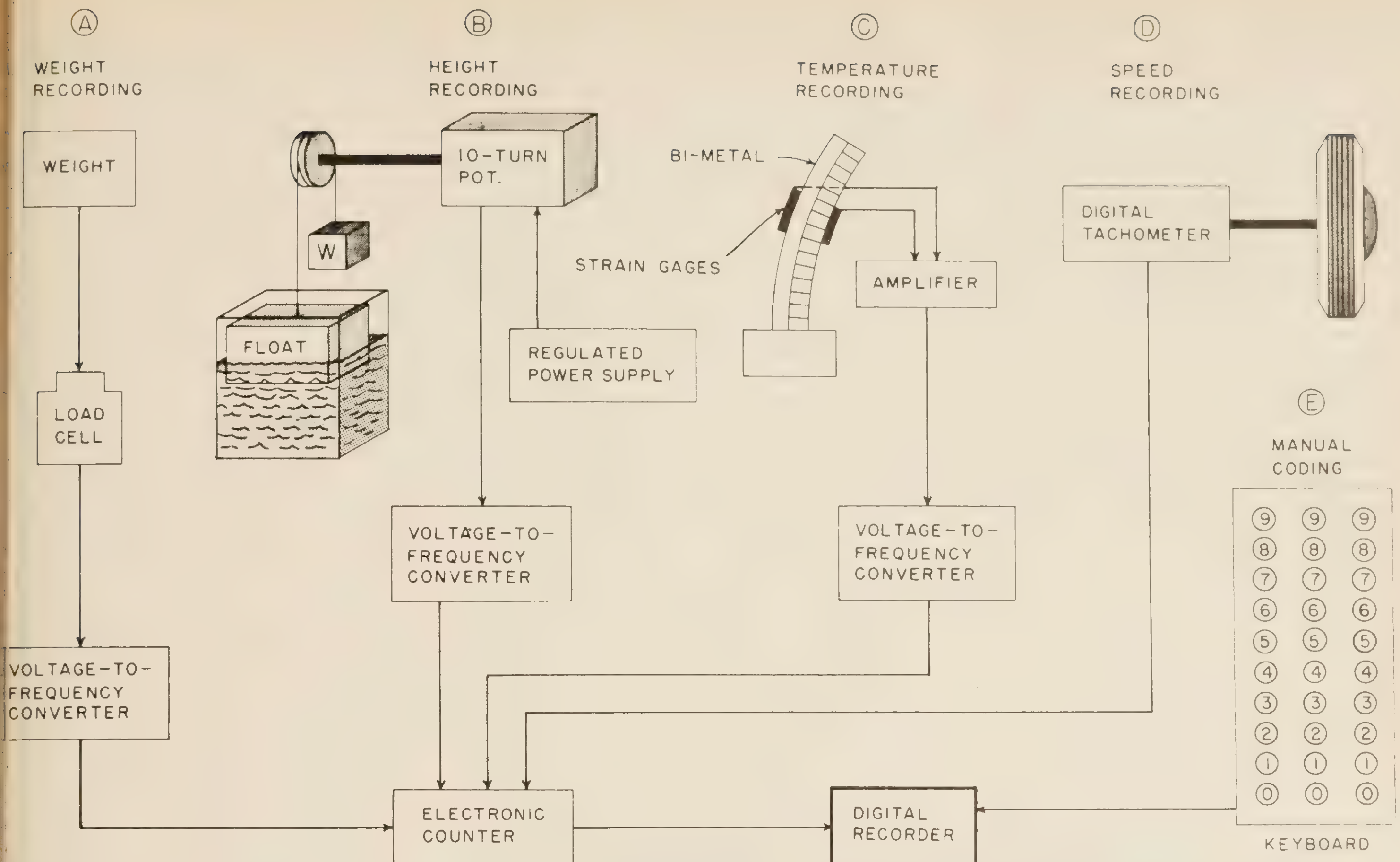
Weight can be directly detected by lo cells. For use in conjunction with dire writing oscillographs, load cells and t necessary oscillator-amplifier systems a commonly used in many highway resear laboratories. Two alternative methods converting typical laboratory weight analog systems to digital recording are possibl Both are equally accurate and the choice w be dictated by future utilization of t equipment which is to be procured.

A direct substitution approach, figure 3, to simply replace the direct writing oscill graph with a digital voltmeter. For a mi mum of data collection, the weight values c be manually recorded from the digital indic tion on the voltmeter. However, since it assumed that large quantities of data are be collected and that a digital recorder h also been obtained, the digital voltmeter w be directly connected to a compatible digit recorder and automatic data collection will accomplished on each print command.

The less direct method, but in ma respects more desirable, diagram A in figure is to substitute a voltage-to-frequency co verter for the direct writing oscillograph. electronic counter unit is also added and used to measure the output frequency a transfer the weight data to the digital record Although requiring an additional unit, t method is favored because the counter u will have many more laboratory applicatio than a digital voltmeter and the origi extra expense will result in later economi Furthermore, the two units will always co bine for a direct measurement of voltage.

Vibration or dynamic strain recording

Vibration or dynamic strain investigati have encouraged the purchase of much of electronic equipment now used in highw and structural laboratories. The usual s tem to record vibration or dynamic strain standard carrier-amplifier equipment w either a direct-writing or galvanometer-t oscillograph output. The digital system these data recording, as shown in figure requires a direct measurement of two valu amplitude and frequency. The amplitude detected by a peak voltmeter for measurem by a standard digital voltmeter and the f quency is directly determined by one of standard electronic counters. Both amplit

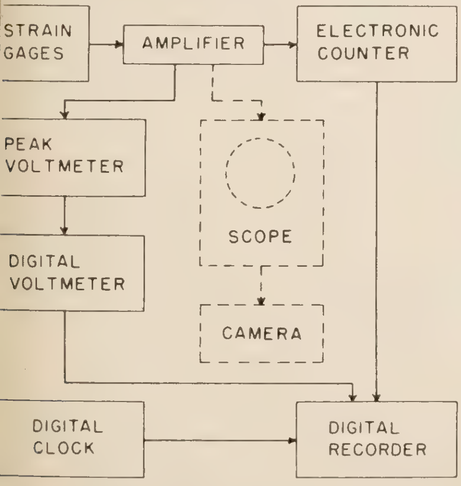


igure 4.—Digital recording diagrams for weight, height, temperature, and speed (and electrical keyboard for coding) using the voltage-to-frequency converter and the electronic counter.

d frequency can then be recorded as desired d the time saved can be best appreciated / those who have counted cycles on analogue arts to determine frequency. The addition a cathode ray oscilloscope will permit the bservation of waveform and a camera will rovide the few necessary illustrations for chnical reports.

eight recording

Liquid levels, large displacements in oper-ing mechanisms, and other height recordings, can be measured and recorded by the system shown as diagram B in figure 4. A precision, 10-turn potentiometer divides the voltage output of the regulated power supply in direct ratio to the level being measured. The print command would usually be controlled by some digital clock and a direct printed record is the result.



igure 5.—Digital recording of vibration or dynamic strain.

Deflection recording

Figure 6 shows a system somewhat similar to that used in recording height but which is more practical for small displacements or deflections. In this system a linear precision potentiometer, or a linear variable differential transformer (LVDT) in a carrier-amplifier system, provides a direct reading of movement. The print command in this instance could be controlled by position detectors "D" to provide a deflection record of a structural member.

Temperature recording

Any system of temperature detection with an electrical output can be adapted for digital recording. Diagram C in figure 4 shows one typical system in which strain gages are attached to a bimetal strip. A standard bridge-amplifier couples such a detector to a digital voltmeter for transfer to the recorder at any desired time. Other detectors, such as thermistors or thermocouples, can be easily accommodated.

Speed recording

Shaft speeds are detected by a tachometer as in analogue systems. However, for digital recording it is generally more convenient to use a digital tachometer rather than converting an analogue output. The common tachometer generator produces an increasing voltage with increasing shaft speed; the digital tachometer produces one or more pulses per revolution of the shaft. The digital recording system is completed by connecting a digital tachometer to an electronic counter which has a time base and gating circuits to count pulses per unit of time. The shaft speed then

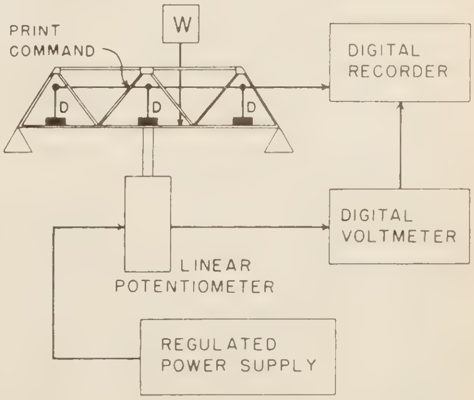


Figure 6.—Digital recording of small displacements or deflections.

becomes direct reading for transfer to the digital recorder. A typical system is shown as diagram D in figure 4.

Manual coding

Notations, which must be entered by hand on an analogue chart, can usually be more conveniently handled by an electrical keyboard in a digital system by entering numerical codes directly in the recorder. This can always be done by providing decades of push buttons connected to produce the proper digital code for the type of recorder used (diagram E in figure 4).

Traffic Impedance Analyzer

It is a rare occasion when a physical investigation requires the recording of only a single channel of information. It is much more likely that the capacity of any given recorder will be strained and a complicated system for programing the data entries will become desirable. However, most problems can be reasonably limited to the capacity of the 11- or 12-digit recorders available.

An example of several data being simultaneously entered on a digital recorder is provided in the *traffic impedance analyzer* developed by the Bureau of Public Roads for speed and delay studies and operating economy studies. This digital data-collecting and recording system is mounted in a motor vehicle, figure 7, and when the vehicle is in motion, at 1-second intervals, prints the vehicle speed in miles per hour, accumulated mileage in three significant figures, time in seconds for a sequence check, and three significant figures of fuel consumption, and provides 2 decades of manual code. These data are shown in a typical recording sample in figure 8.

Figure 9 presents a block diagram illustration of the traffic impedance analyzer and simplifies the explanation of its operation. As both speed and delay studies and operating economy studies require speed and distance to be recorded as a part of the data, primary consideration was given to recording these quantities. The speedometer cable of standard American automobiles is designed to make 1,000 revolutions per mile. On this basis a special digital tachometer was designed which would provide direct speed and distance outputs. For the measurement of speed, a disc with 36 holes near its outer edge was rotated by a shaft input. With a light source on one side of the disc and a photoelectric cell on the other, electronic pulses in direct representation of speed in miles per hour could be generated each one-tenth second with a shaft input rate of 1,000 revolutions per mile. A second disc with one hole near its outer edge was coupled to the first disc by a 10:1 gear reduction unit. A second photoelect cell on the outer side of the second disc the fore generated an electronic pulse for ea one-hundredth of a mile of vehicle trav The shaft input of this digital tachometer w coupled to the regular speedometer ca of the automobile by a 1:1 geared "T" the speedometer head.

The electronic pulses from the speed tecting photoelectric cell were connected the input of an electronic counter. T counter included a quartz crystal time b and generated usable pulses at intervals ⅒, 1, and 10 seconds. The ⅒-second pul were utilized internally to operate the *co*

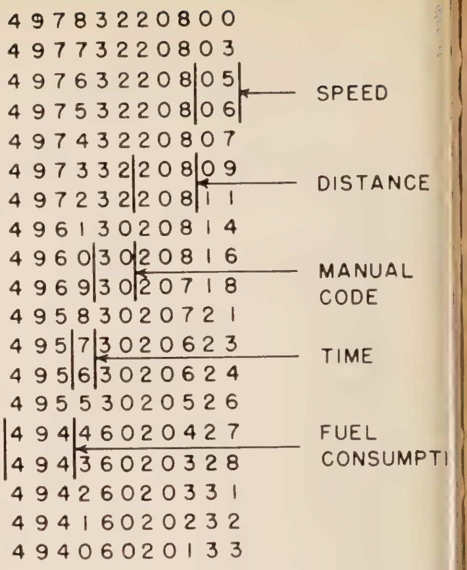

```
4978322080 0
4977322080 3
4976322208|05|
4975322208|06|
4974322080 7
49733 2|208|09
49723 2|208|11
4961302081 4
4960|30|208 16
4969|30|207 18
4958302072 1
495|7|3020623
495|6|3020624
4955302052 6
|494|46020427
|494|36020328
4942602033 1
4941602023 2
4940602013 3
```

Figure 8.—A typical recording sample fr the traffic impedance analyzer.

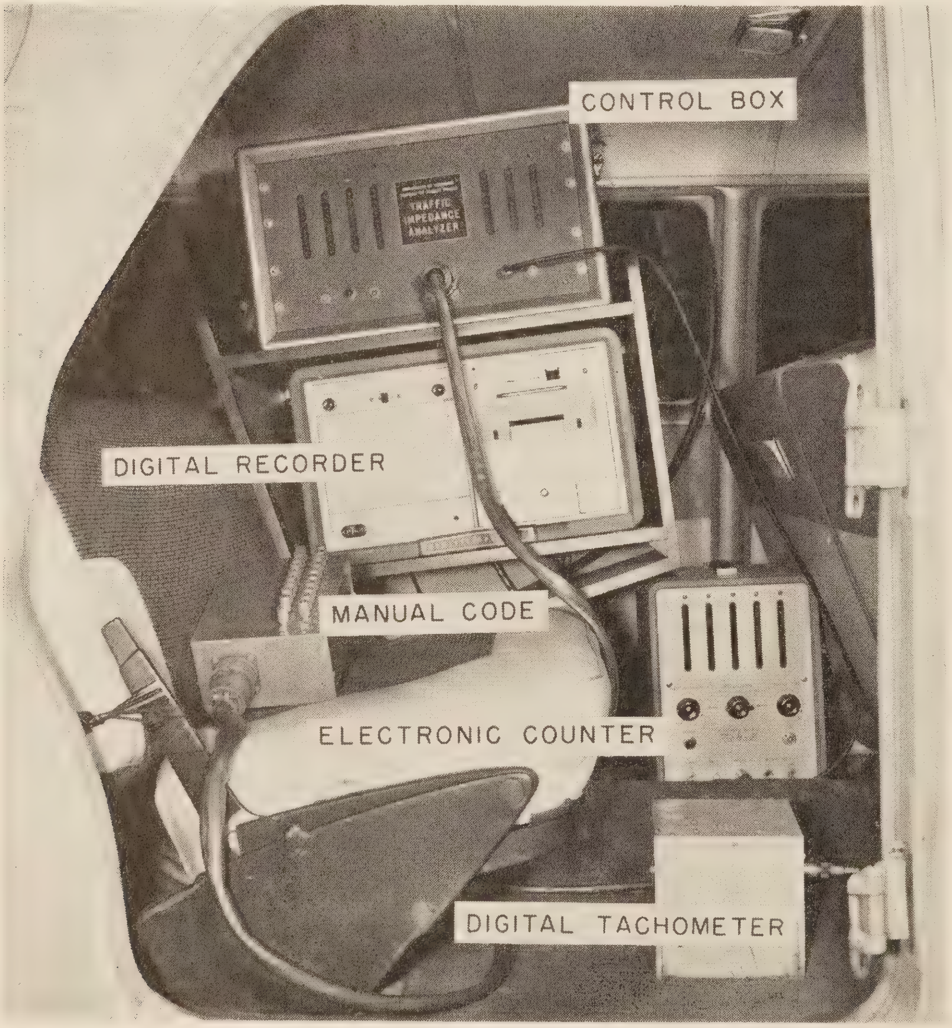


Figure 7.—Traffic impedance analyzer mounted on rear seat of a passenger car.

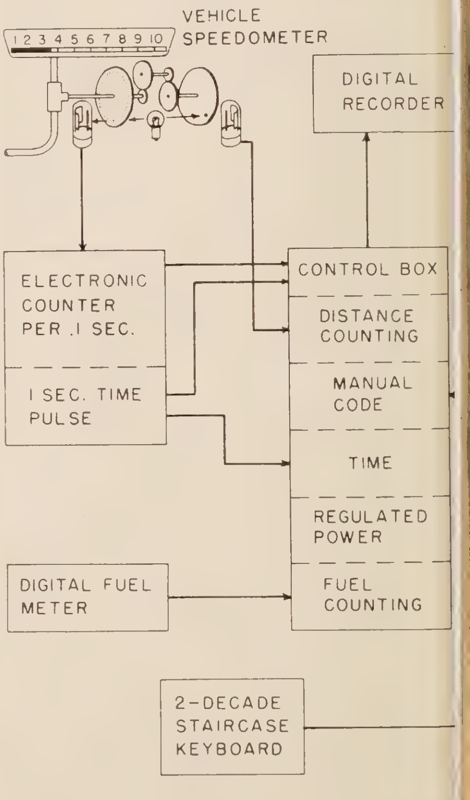


Figure 9.—Block diagram of the operati of the traffic impedance analyzer.

and *stop* gates so that the number of *speed* pulses for any $\frac{1}{10}$-second period could be accurately counted. The 1-second pulses were connected to the control box and used to nitiate a recording period. Therefore, at the beginning of each second the electronic counter was reset and the *count* gate opened to accumulate *speed* pulses. One-tenth second later the *count* gate was closed and a print command recorded the speed of the vehicle and all other data which were available at the recorder inputs.

The electronic pulses from the distance-detecting photoelectric cell were connected to 3 decades of electronic counting in the control box where they were accumulated. This distance accumulation was continually available for recording.

The traffic, geometric design, control, weather, and other pertinent data could be coded by 2 decades of push buttons which would transfer as digits to the recorder at any printing cycle.

One decade of time counting was provided in the control box as a printing sequence check. The circuitry also provided for time counting to be extended to 4 decades as an alternative to fuel recording when it was more convenient, for field observation, to have elapsed time recorded during speed and delay studies.

To record fuel consumption a digital fuel meter was mounted on the engine of the motor vehicle between the fuel pump and carburetor. The digital fuel meter used in this instance produced an electrical pulse for each $\frac{1}{2000}$-gallon of gasoline passing through it. These pulses were accumulated in 3 decades of electronic counters in the control box so that a total of fuel consumption was available for transfer to the recorder at each print command.

The complete equipment was powered by a 1,250-watt gasoline-driven generator weighing 85 pounds which was carried on a standard roof-mount luggage rack. This self-contained unit illustrates the advantages of digital recording and the possibilities of adapting a few standard electronic instruments to the myriad data collecting problems encountered by the highway research engineer.

Fully automatic data reduction can, of course, be realized by adding standard tape punch units to the digital recorders discussed herein. The punched tape then may be used as a computer input or its data may be automatically transferred to magnetic tape or punch cards as individual cases require. The equipment to accomplish these processes are available to those who may wish to extend their systems to include them; but, for the purposes of this article, it was believed that a simple introduction to digital recording would better serve the greater number of highway engineers.

Driver Tension Responses

(Continued from page 58)

Not only did the observation program eliminate temporal differences, it also eliminated intensity differences within each traffic event. It was assumed that all occurrences of an event represented the same stimulus intensity. In essence, this procedure eliminates within stimulus class variability. It is quite obvious that the affective intensity of an event may be quite variable, depending upon a variety of temporal and spatial factors in the environment as well as perceptual and emotional factors in the driver. It should be obvious, therefore, that the method used in this study oversimplified the nature of the traffic interferences and simply placed them into 1 of 8 qualitative categories, none of which had any measure of intensity attached. Thus, precision of stimulus measurement was sacrificed to obtain reliability of observation.

Within the limitations outlined, this study indicates that the two arterial routes studied differ in the rate and magnitude of galvanic skin response aroused in driving. The results, in general, indicate that the GSR may be a promising means for using driver behavior to discriminate between different kinds of streets and the interferences on them. There are, however, several statistical and methodological problems inherent in the use of the GSR which requires further research and which, consequently, restrict its operational utility at the present time.

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Highway Illumination and Delineation

(Continued from page 66)

of roadside delineation with or without illumination, and the need for using adequate intensity of illumination if highway lighting is to be provided. Above all, the experience gained will be most helpful in the planning and conducting of future highway lighting research, even if only in negative fashion. It appears that criteria other than those used in this report must be studied to evaluate properly the effect of highway lighting on traffic operations.

Editor's note: The detailed tables containing the schedule of field operations and the average speeds, placements, headways, and clearances for all motor vehicles under the nine conditions of illumination and delineation, are not published here since they presumably are not of interest except to researchers in this subject. Copies of the tables are available to those who may have specific use for them from the Division of Traffic Operations, Bureau of Public Roads, Washington 25, D.C.

Introduction to Highway Hydraulics: A Motion Picture

The Bureau of Public Roads, U.S. Department of Commerce, in cooperation with the Colorado State University, recently produced the motion picture, *Introduction to highway hydraulics*. This film illustrates basic hydraulic principles related to open-channel flow design in highway engineering.

Flow illustrations of the hydraulic principles are shown by laboratory models and field scenes. Various scenes depict the principles of continuity of flow, energy, and momentum, which are the basic laws governing any open-channel flow problems. Use is made of field scenes to illustrate where the principles apply in highway engineering.

Introduction to highway hydraulics is a 16mm. sound and color film with a running time of 21 minutes. Prints may be borrowed for showing by any responsible organization by request addressed to Mr. Ray B. Dame, Head, Photographic Section, Bureau of Public Roads, Washington 25, D.C. There is no charge other than for express or postage fees. Request should be sent well in advance of the desired showing, and alternate dates indicate if possible. Immediate return after eac booking is necessary, so that all requests ma be fulfilled.

Prints of the film may be purchased a $86.47 per copy, the price including film, ree can, shipping container and postage withi the United States. Inquiries on purchasin film prints should also be addressed to Mr. Ra B. Dame, Head, Photographic Section, Bu reau of Public Roads, Washington 25, D.C Payment should not be sent with the inquiry

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