The subgrade moisture contents, 8 months after base construction and 85 months after base construction, expressed as percentages of the plastic limit moisture are as follows:

Layer Thickness	2 ft. from Edge		8 ft. from Edge	
	8 Months	85 Months	8 Months	85 Months
in.				
0–6	100	105	78	93
6–12	107	112	89	104
12–18	110	111	97	108

Considering this information, in view of the fact that the plastic limits of cohesive soils are approximately equal to the critical moisture content, i.e., the moisture value above which increments of moisture result in much greater reductions in load bearing power than do similar increments of moisture below this value, we are of the opinion that a uniform cross section thickness is unbalanced for bases of these types unless some auxilliary means is provided for either stabilizing the outer edge of the subgrade or preventing the excessive accumulation of water at this location.

Limited additional data are available which indicate a possibility that the type of base or even the method of construction may critically influence the subgrade moisture content and its relation to the lower plastic limit of the subgrade soil. Such data need to be supplemented before they can be considered significant, but further studies of this phase of the subject are considered desirable.

STUDIES OF MOTOR VEHICLE OPERATION ON LIGHTED AND UNLIGHTED RURAL HIGHWAYS IN NEW JERSEY

A Project of the Committee on Highway Lighting Research

Reported by O. K. Normann,[1] *Senior Highway Engineer, Public Roads Administration*

SYNOPSIS

As part of the program of the Committee on Highway Lighting Research, the Public Roads Administration in cooperation with the Electrical Division of the New Jersey State Highway Department conducted studies to determine the effect of highway lighting on the movement of vehicles over 2-lane, 3-lane, and wider rural highways.

Driver-behavior data were obtained simultaneously on adjacent sections of lighted and unlighted highway by employing electrical equipment which recorded the travel speeds and transverse and longitudinal spacings and clearances between vehicles traveling in the same and opposing directions.

Preliminary tests were also conducted employing apparatus designed to compare the daytime nervous tension of drivers and passengers with their nervous tension at night on the lighted and unlighted sections. During these tests, a car equipped with a number of special recording devices was used for the first time. It appeared to be a normal five-passenger sedan but in back of the front seat were located the devices used to record the readings of a number of well concealed instruments. These instruments obtained information on a number of items that could be measured which it was believed would be related to the nervous tension of the driver and the nervous tension of a passenger in the front seat.

[1] Chairman, Subcommittee on Test Projects. Other members include Mr. H. F. Ilgner, Superintendent and Chief Engineer, Bureau of Electric Service, Milwaukee, Wisconsin and Mr. E. J. Reeder, Head, Public Safety Section, U. S. Engineer Department, Oak Ridge, Tennessee.

The results of the studies on tangent sections of rural highway where there were few pedestrians, few property entrances, and low traffic densities were:

1. Highway lighting does not affect travel speeds.
2. Based on transverse positions and clearances between vehicles, the behavior of drivers at night conforms more nearly to their daytime practices when the highway is lighted than when the highway is unlighted. The difference, however, is slight.
3. Certain driving practices at night which tend to cause accidents are reduced a measurable amount by providing highway illumination. This is verified by the actual accident rate as well as by the potential accident hazard as determined by the driver-behavior studies. The driving practices that seem to be directly affected are: (1) the tendency of drivers to follow too closely behind a preceding vehicle traveling at the same speed, and (2) failure of drivers to keep their vehicles to the right of the center line when meeting other vehicles on a 2-lane highway.
4. With the exception of the hand bulb, the devices used in an attempt to measure nervous tension recorded the desired data; but the significance of the difference between the average values recorded for the lighted and unlighted highway sections cannot be evaluated without further research.

Insufficient evidence was provided by these studies to justify continuous lighting on long tangent sections of rural highway.

Extensive research will be required to develop a device or combination of devices that will measure some factor which is directly related to a driver's nervous tension and to establish a reliable correlation that can be used in evaluating the more intangible benefits derived from highway lighting.

Evaluating the benefits resulting from lighting a rural highway in terms that can be used to justify the installation and maintenance costs connected therewith is not possible at the present time, primarily because too little is known regarding the full effect that artificial lighting has on traffic movement, accident rates, and driving efficiency and comfort at various traffic densities.

It is a generally accepted fact that night accident rates are much higher than daytime rates, but what are not known, at least to the extent necessary to determine whether or not the cost of lighting long sections of rural highway can be justified, are (1) the correlation between rural accident rates and lighting, (2) the effect of lighting on the economic utility of highways, and (3) the differing effects of daylight, darkness, and highway lighting on motorists' driving behavior, habits, and comfort.

Accident data have been compiled for periods before and after lights were installed at a large number of highway locations, but it has not been possible to arrive at conclusive results for long continuous sections of rural highway from such studies. Usually a number of other improvements or changes which may have affected the accident rates were made at the time the lights were installed, or the available accident and traffic data were not sufficiently complete to use as the basis for such a study. Accordingly, the Committee on Highway Lighting in 1940 outlined a program of comprehensive accident and driver-behavior studies to be conducted on special test sections of representative 2- and 4-lane highways at least 10 miles long, and preferably 30 miles long. The minimum test period was to be one year without lighting and one year with lighting. The plans included complete traffic counts, recordings of speed, studies of driver behavior, and the keeping of an accurate record of traffic accidents by a special 24-hour patrol.

Due primarily to the war, the committee was unable to work out suitable arrangements for these complete studies. At their December 1943 meeting it was decided to proceed with less elaborate studies on available sections of highway with lighting installations that were not in operation due to the war emergency but which could be turned on for sufficient periods to make driver-behavior studies.

It was also decided to study and develop techniques for measuring the nervous tension of drivers and passengers at night on lighted and unlighted sections of highway. Studies of this type are considered by the committee to be an important part of the entire problem of evaluating the full benefits attained by lighting a rural highway. Any factor which decreases driving strain or tends to reduce the tense reactions of the driver under certain circumstances will influence driving comfort and affect highway safety.

With the cooperation of the Electrical Division of the New Jersey State Highway Department, the Public Roads Administration during 1944 conducted a series of studies that were designed to supply information which would be useful in evaluating the benefits received by lighting a rural highway. These studies will be considered under three separate phases, although all are related to the same problem. These are as follows:

1. Driver behavior during daylight and at night on lighted and unlighted sections of 2-lane, 3-lane, and wider highways.
2. Tests of special equipment designed to measure, under actual operating conditions, a number of items which it was believed could be used as indices to compare the driver's or passenger's nervous tension when traveling at night over sections of lighted and unlighted highways.
3. An analysis of day and night accident records for the lighted and unlighted sections of 2-lane highways on which the driver-behavior studies were conducted.

SIMULTANEOUS STUDIES AT LIGHTED AND UNLIGHTED LOCATIONS

The first phase involved the use of electrical equipment developed by the Public Roads Administration[2] to record the speed and transverse position of each vehicle passing the study sites, the clearances between vehicles as they met while traveling in opposing directions, transverse clearances between vehicles overtaking and passing other vehicles and longitudinal clearances between vehicles following other vehicles moving at the same speed.

To obtain directly comparable data for lighted and unlighted highway conditions, the driver-behavior studies were conducted simultaneously at two locations on the same highway where the roadway design features appeared to be identical in all respects with the exception that one was lighted and the other unlighted. The advantage of conducting comparative studies at the same time was considered more important than making studies with and without lighting at exactly the same location because differences in such factors as weather conditions and type and volume of traffic were entirely eliminated. As an additional assurance that the section had identical characteristics except for the lighting, and to furnish a base with which the nighttime driver performance could be compared, the recording equipment was operated about three hours during daylight in addition to the night study which started shortly after complete darkness occurred and continued until after midnight. In each case, the selected study site was at least 0.6 mile, and generally a mile or more from any change in the type of illumination, and in no case were there any major crossroads or small town between the two comparable sites.

By a critical examination of driver behavior under the various conditions, it was possible to obtain the difference between daytime performance and nighttime performance on the unlighted sections. The effectiveness of the lighting could then be measured by the degree to which driver performance on the lighted sections at night approached daytime performance. This method of evaluating the effects of highway lighting on safety is not as direct an approach as an analysis of accident records. However, to obtain a reliable index from an accident analysis would require a comparison of accurate and complete records for long stretches of highway with identical design features and traffic volumes for a period of several years because relatively few accidents occur per mile per year on any one section of modern highway. As yet, such a comparison has not been possible because of the limited mileage of rural highway with continuous lighting.

Table 1 shows the locations of the eight sites where driver-behavior studies were conducted during the July 4 and Labor Day week ends or shortly thereafter. These periods were selected so that data could be recorded for the highest possible traffic densities under present gasoline restrictions. At sites 1 and 2 information was recorded for southbound traffic only, consisting entirely of passenger cars coming primarily from New York City and headed for the beaches in New Jersey.

[2] "New Techniques in Traffic Behavior Studies," by E. H. Holmes and S. E. Reymer, *Public Roads*, April 1940.

Prior to reaching site 2 where 400-candlepower lights were spaced at 175-ft. intervals, the traffic had been traveling on U. S. Route 1 which was also lighted. The lighted sections on State Route 35 ended about 400 ft. beyond the underpass at site 2 and traffic traveled 2 miles over the unlighted highway before reaching the underpass at site 1.

Sites 3 through 6 were alternate locations along State Route 44 (U S 130) just north of the Pennsville-Newcastle Ferry. Data were recorded for traffic in both directions of travel on the 20-ft. concrete surface with 8-ft. bituminous shoulders. At site 6, 4,000-lumen lights were spaced at 200-ft. intervals on alternate sides of the road and overhung the surface 5 ft. at a height of 25 ft. The lights at site 4, which were installed as a protective measure along the fence, were 6,000-lumen units mounted at 150-ft. intervals at the Delawâre Ordnance Depot which paralleled the highway. Normally, only every third light is in operation, but for these studies all were placed in operation on July 4 and 5, thus providing a somewhat more uniform distribution and greater intensity of light to the road surface than the highway lights at site 6.

Sites 7 and 8 were on the White Horse Pike. Under normal conditions, the entire 57 miles of this highway between Camden and Atlantic City are lighted, but since 1941 only the lights located at intersections, in urban areas, and on sharp curves have been in operation. Through the courtesy of the Atlantic City Power Company, lights on a 2.5-mile rural section of this route west of Absecon, New Jersey, were placed in operation from September 1 through September 7, 1944. Study site 7 was near the center of a 2.5-mile lighted section just west of Absecon, New Jersey, while site 8 was 3 miles farther west and near the center of the 2.5-mile section lighted with 4,000-lumen units spaced at 200-ft. intervals on alternate sides of the road and overhanging the 3-lane surface about 10 ft. at a height of 25 ft.

TABLE 1

DESCRIPTION AND LOCATION OF SITES INCLUDED IN DRIVER BEHAVIOR STUDIES ON UNLIGHTED AND LIGHTED RURAL HIGHWAYS

Site Number	Light Condition	Number of Traffic Lanes	Surface Width in Feet[a]	Alinement	State Route Number	Location	Dates of Study in 1944
1	Unlighted	6-divided	32[b]	At underpass	35	2.3 miles S. of Green St. traffic circle	July 1
2	Lighted	"	32[b]	" "	35	0.3 " " " " " " "	"
3	Unlighted	2	20	Level tangent	44	4.8 miles N. of Junction with S. R. 48	July 2, 4, & 5
4	Lighted	2	20	" "	44	2.6 " " " " " " "	"
5	Unlighted	2	20	Level tangent	44	3.5 miles N. of Pennsville, N. J. Ferry	July 6, 7, & 9
6	Lighted	2	20	" "	44	2.3 " " " " " "	"
7	Unlighted	3	30	Level tangent	43	1.5 miles W. of Absecon, N. J.	Sept. 2, 3, & 4
8	Lighted	3	30	" "	43	4.5 " " " " " "	"

[a] Concrete surfaces.
[b] Between curbs for each direction of travel.

DATA FOR 23,000 VEHICLES ANALYZED

Table 2 shows that data for 23,034 vehicles have been analyzed in order to compare vehicle speeds and transverse positions on lighted highways with those on unlighted highways. The data analyzed include approximately two-thirds of the total data recorded during the field studies. To obtain a comparison between daytime and nighttime operation, it was necessary to exclude from the analysis data that were recorded during the higher traffic density periods in the daytime and during the lower traffic density periods at night. By this procedure, the difference between the average traffic densities in the daytime and at night has been reduced, but the daytime densities are still considerably higher than the nighttime densities. At none of the locations, however, was the traffic density high enough, either during the daytime or at night, to cause congestion or influence travel speeds to any appreciable extent.

RESULTS OF STUDIES ON 6-LANE HIGHWAY

The lights on the 6-lane highway had no effect on vehicle speeds. Figure 1 shows that

TABLE 2
NUMBER OF VEHICLES INCLUDED IN STUDIES

Type of Roadway	Light Condition	Site Number	Study Time		Average Traffic Volume		Vehicles Included	
			Day	Night	Day	Night	Day	Night
			hours	*hours*	*V.P.H.*	*V.P.H.*	*number*	*number*
6-lane divided[a]	Unlighted	1	0.4	2.0	1,070	504	446	1,009
	Lighted	2	0.5	2.4	1,015	550	459	1,101
2-lane	Unlighted	3 & 5	14.7	16.6	259	210	2,810	3,488
	Lighted	4 & 6	11.9	13.2	251	213	2,986	2,815
3-lane	Unlighted	7	6.1	5.4	441	277	2,680	1,500
	Lighted	8	5.4	4.9	442	279	2,380	1,360
Total unlighted			21.2	24.0			5,936	5,997
Total lighted			17.8	20.5			5,825	5,276
Grand total....................			39.0	44.5			11,761	11,273

[a] Study time and average traffic volume are shown for one direction of travel.

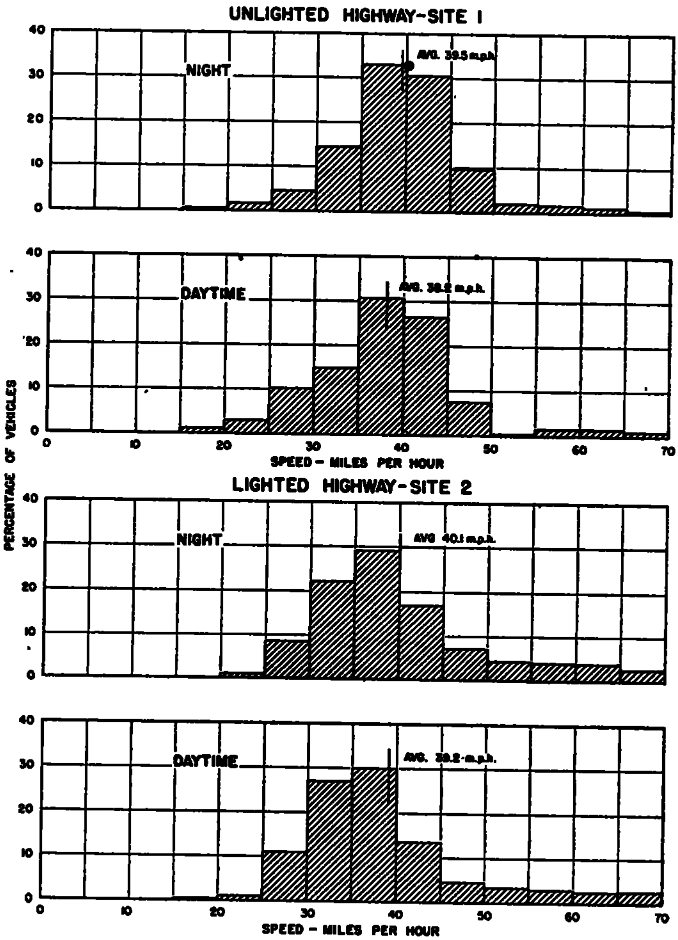

Figure 1. Distribution of Vehicle Speeds for Southbound Traffic at Grade Separations on Unlighted and Lighted Sections of a 6-Lane Divided Highway.

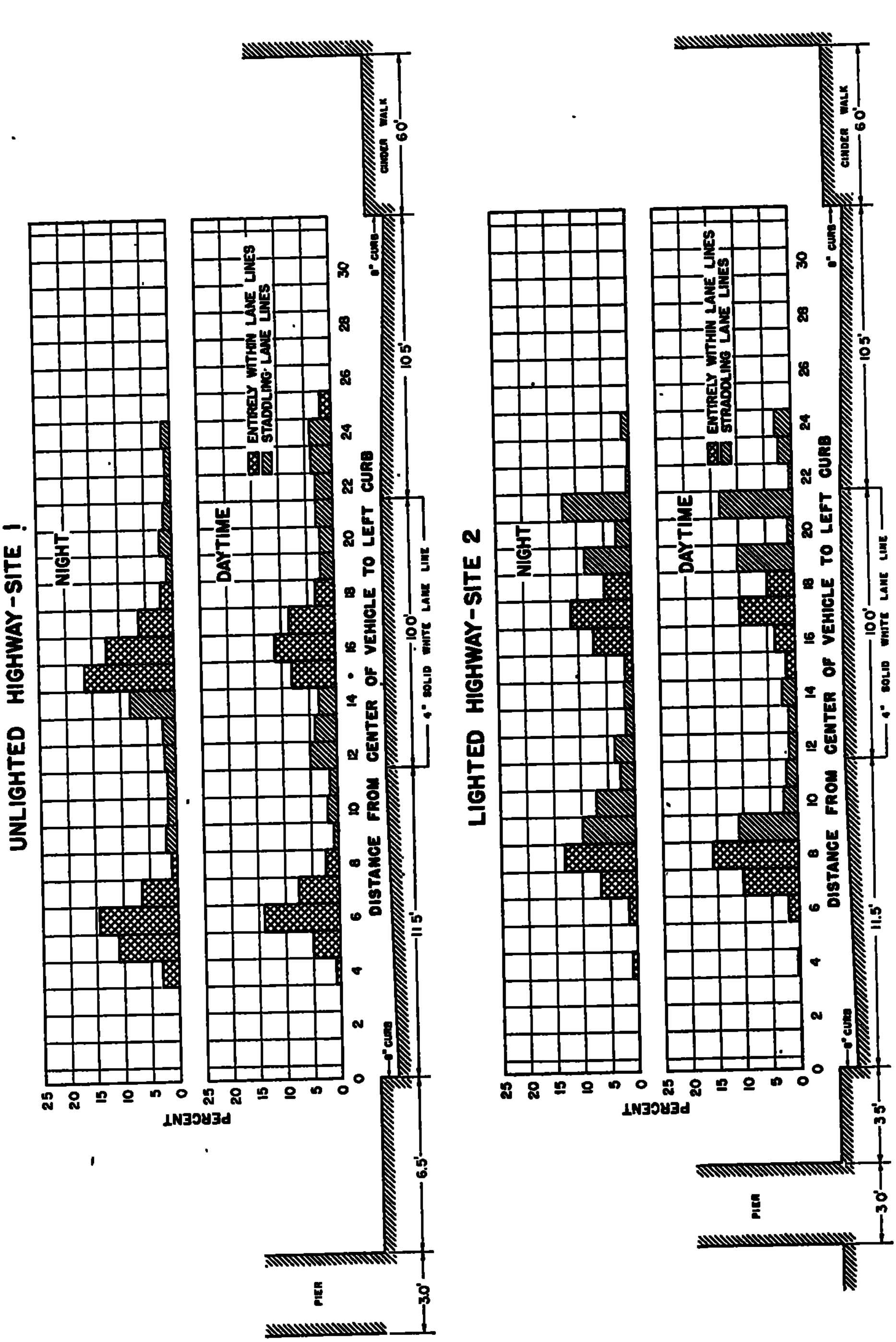

Figure 2. Distribution of Vehicle Placements for Southbound Traffic at Grade Separations on Unlighted and Lighted Sections of a 6-Lane Divided Highway.

average speeds at both the unlighted and lighted locations were about one mile per hour higher at night than in the daytime. There was also practically the same difference between the daytime and nighttime speed distributions at the lighted location as at the unlighted location.

Figure 2 shows the distribution of transverse positions for southbound traffic at the two grade separations. In the daytime and at night, fewer drivers used the left-hand lane at the location with lights than at the location without lights. This difference was caused by the vertical piers, located 3.5 ft. from the pavement edge at the lighted underpass and 6.5 ft. from the edge at the unlighted underpass. Numerous other studies have

TABLE 3
DISTRIBUTION OF VEHICLES BY LANES AT GRADE SEPARATIONS ON UNLIGHTED AND LIGHTED SECTIONS OF 6-LANE DIVIDED HIGHWAY

Position	Unlighted Highway		Lighted Highway	
	Day	Night	Day	Night
	Percentage of vehicles			
In left-hand lane	30.3	36.2	28.2	22.4
Straddling left lane line	16.6	17.6	20.7	26.7
In center lane	31.7	37.1	20.4	25.0
Straddling right lane line	19.4	9.1	30.7	25.9
In right-hand lane	2.0			
Total	100.0	100.0	100.0	100.0
Average distance centers of vehicles were from left-hand curb—Feet	13.8	12.1	14.1	13.9
Average speed—miles per hour	38.2	39.5	39.2	40.1

also shown that it is common practice for drivers to shy away from vertical obstructions that are less than 6 ft. from the edge of the surface. The right-hand lane was used by comparatively few drivers, especially at the unlighted underpass. In effect, it was comparable to the paved shoulder on the other sections of the highway.

By comparing the day and night placement distributions at the two sites as shown by Figure 2 and Table 3, it may be seen that driver behavior was practically identical during both periods at the location with lights, while there was a noticeable difference at the unlighted location. The average change in transverse position with darkness was reduced from 1.7 ft. to 0.2 ft. by the lights. Although this fact cannot be interpreted to justify narrower lane widths where lights are employed, it is significant that the highway lights did reduce the difference between daytime and nighttime operating characteristics on this multi-lane highway.

VEHICLES CLASSIFIED BY TYPE AND PROXIMITY TO OTHER TRAFFIC ON 2-LANE HIGHWAY

The two sets of equipment used while conducting studies simultaneously at unlighted and lighted sections of the 2-lane highway were not identical, although they both recorded the speed and transverse position of the vehicles. It was possible to correlate the speed of each vehicle with its transverse position and sequence as it passed the study location from the recordings made by one unit, while this was not possible from the recordings made by the other unit. The second unit recorded the transverse position on a graphic chart as it obtained a cumulative count of the number of vehicles in each of 20 speed groups ranging from 19 to 70 miles per hour. By alternating these two units at the unlighted and lighted locations, it was possible to correlate the speed with the transverse position for approximately half of the data recorded at each location and for about two-thirds of the data included in the analysis.

Previous studies of this type have shown that the speed and transverse position which a driver assumes on a 2-lane highway 20 ft. wide is governed to an appreciable extent by other traffic on the highway. For this reason, the vehicles included in the analysis of driver behavior on unlighted and lighted sections of 2-lane highways have been classified into the groups listed in Table 4 which also shows the number of vehicles included in each classification. Busses and trucks with dual rear tires were classified as commercial vehicles. Light delivery trucks and station wagons were included with the passenger cars. Vehicles that were at a time spacing in excess of 6 sec. from the preceding vehicle traveling in the same direction and had not met or would not meet another vehicle traveling in the opposing direction within 5 sec. were considered "free moving." A vehicle was classified as meeting oncoming traffic if the meeting took place within 1½ sec. of the time its speed and transverse position were recorded. Whenever a vehicle met two vehicles within this time interval, its body clearance was measured to the closer of the two vehicles. This is the reason that the number of passenger cars meeting commercial vehicles differs slightly from the number of commercial vehicles meeting passenger cars in Table 4. Consequently, the average clearance between bodies when passenger cars meet commercial vehicles is not always the same as for commercial vehicles meeting passenger cars (Table 7).

TABLE 4

VEHICLES INCLUDED IN GROUPS USED FOR ANALYSIS OF DRIVER BEHAVIOR ON UNLIGHTED AND LIGHTED SECTIONS OF 2-LANE RURAL HIGHWAY

Group	Unlighted Highway		Lighted Highway	
	Day	Night	Day	Night
	number	*number*	*number*	*number*
Free-moving vehicles:				
Passenger cars	1,317	1,159	1,093	620
Commercial vehicles	317	369	249	235
Vehicles meeting oncoming traffic:				
Passenger cars				
Meeting passenger cars	571	253	416	168
Meeting commercial vehicles	109	62	101	41
Commercial vehicles				
Meeting passenger cars	110	65	92	42
Meeting commercial vehicles	41	39	23	18
Speed correlated with placement	2,038	2,274	1,698	1,134
Transverse placement analyzed	2,810	3,488	2,986	1,635
Total used to obtain average speeds	2,810	3,488	2,986	2,815

There was close agreement between daytime and nighttime speeds on both the lighted and unlighted sections of 2-lane highways. The only significant change due to darkness, as shown by Table 5, was an average reduction of 3.4 miles per hour in the speed of passenger cars as they met commercial vehicles on the unlighted sections. An analysis of the speed distribution on the lighted and unlighted sections indicates that the lights had little if any effect on the speed range. For example, on the unlighted sections 6.3 per cent of the free-moving passenger cars exceeded 50 miles per hour in the daytime and 5.8 per cent exceeded that speed at night. Corresponding values for the lighted section were 7.7 per cent and 7.3 per cent, respectively, an insignificant difference of about 0.4 per cent in each case.

It is interesting to note that the speeds of vehicles meeting other vehicles are generally as high as the speeds of the free-moving vehicles. In fact, both day and night speeds of commercial vehicles when meeting other commercial vehicles were higher than the speeds of such vehicles when free moving.

LIGHTS HAVE A SLIGHT EFFECT ON TRANSVERSE POSITIONS ON 2-LANE HIGHWAYS

Table 6 shows the positions that the centers of the vehicles occupied with respect to the right edge of the 20-ft. pavement. On an average, free-moving vehicles (those uninfluenced by other traffic) occupied a space centered approximately half a foot to the left of the center of their right-hand lane. When meeting other vehicles they moved to the right, occupying a space that was, on an

TABLE 5

AVERAGE SPEEDS OF VEHICLES ON UNLIGHTED AND LIGHTED SECTIONS OF 2-LANE RURAL HIGHWAY

Group	Unlighted Highway			Lighted Highway		
	Day	Night	Difference	Day	Night	Difference
	miles per hour			*miles per hour*		
Free-moving vehicles:						
Passenger cars	38.9	38.0	−0.9	38.8	37.9	−0.9
Commercial vehicles	38.5	36.9	−1.6	37.3	38.3	1.0
Vehicles meeting oncoming traffic:						
Passenger cars						
Meeting passenger cars	37.6	38.0	0.4	38.5	38.0	−0.5
Meeting commercial vehicles	41.3	37.9	−3.4	40.1	39.6	−0.5
Commercial vehicles						
Meeting passenger cars	37.1	36.8	−0.3	38.6	38.7	0.1
Meeting commercial vehicles	40.3	40.4	0.1	39.1	40.2	1.1
All traffic	38.7	37.7	−1.0	38.1	37.5	−0.6

average, approximately in the center of their right-hand lane. The average transverse positions at night were somewhat different from those in the daytime for corresponding vehicle groups. The difference is, however, slightly less at the lighted than at the unlighted locations.

Table 7 shows the average clearance between the bodies of vehicles meeting one another. Total body widths of 6 ft. for passenger cars and 8 ft. for commercial vehicles were used when calculating these values from the original data showing the positions of the right and left wheels of each vehicle. When comparing the clearances between vehicles as obtained by these studies on a 20-ft. surface with 8-ft. bituminous shoulders, it is well to remember that from a comprehensive study of 2-lane roads it was found that this cross section is equivalent to a 22-ft. pavement with grass or gravel shoulders.[3]

These same studies also show that the clearance between vehicles on a 22-ft. surface is only 1 ft. greater than on a 20-ft. surface. It would be reasonable, therefore, to assume that the lights had a considerable effect on driver behavior if the difference in clearances on the lighted and unlighted sections was found to be only a few tenths of a foot.

Table 7 shows that the difference between vehicle clearances at night as compared with the clearances in the daytime was on an average only about half as large for the lighted highway as for the unlighted highway. The most significant point, however, is that clearances in general were greater at night than in the daytime on the unlighted highway, and less at night than in the daytime on the lighted highway. This indicates that drivers require a wider surface width at night when there are no lights than they need in the daytime, or when highway lights are provided, to assure that their clearances to oncoming traffic will be adequate. Based on a difference of 1 ft. for 20- and 22-ft. surfaces, the difference of 0.4 ft. between the clearances at night on the lighted and unlighted sections for the more

TABLE 6

AVERAGE TRANSVERSE POSITIONS OF VEHICLES ON UNLIGHTED AND LIGHTED SECTIONS OF 2-LANE RURAL HIGHWAY

Group	Unlighted Highway			Lighted Highway		
	Day	Night	Difference	Day	Night	Difference
	Distance centers of vehicles were from right edge of 20-ft. pavement—ft.					
Free-moving vehicles:						
Passenger cars	5.5	5.6	0.1	5.4	5.5	0.1
Commercial vehicles	5.5	5.8	0.3	5.7	5.8	0.1
Vehicles meeting oncoming traffic:						
Passenger cars						
Meeting passenger cars	4.9	4.8	−0.1	4.8	4.8	0.0
Meeting commercial vehicles	4.7	4.6	−0.1	4.5	4.5	0.0
Commercial vehicles						
Meeting passenger cars	5.2	4.9	−0.3	5.1	5.3	0.2
Meeting commercial vehicles	4.6	4.7	0.1	4.9	4.9	0.0

TABLE 7

AVERAGE CLEARANCE BETWEEN VEHICLES TRAVELING IN OPPOSING DIRECTION ON UNLIGHTED AND LIGHTED SECTIONS OF 2-LANE RURAL HIGHWAY

Group	Unlighted Highway			Lighted Highway		
	Day	Night	Difference	Day	Night	Difference
	Clearance between bodies of vehicles—ft.					
Passenger cars meeting passenger cars	4.2	4.3	0.1	4.4	4.3	−0.1
Passenger cars meeting commercial vehicles	3.1	3.5	0.4	3.3	3.1	−0.2
Commercial vehicles meeting passenger cars	3.1	3.5	0.4	3.4	3.2	−0.2
Commercial vehicles meeting commercial vehicles	2.8	2.6	−0.2	2.3	2.2	−0.1

[3] "Effect of Roadway Width on Traffic Operation," "1.—Two-lane Concrete Roads," by A. Taragin, *Proceedings*, Highway Research Board, Vol. 24 (this volume), p. 292.

critical meetings involving commercial vehicles would be comparable to a difference of 0.8 ft. in the total surface width.

POTENTIAL ACCIDENT RATE HIGHER ON UNLIGHTED HIGHWAYS

The average clearance between vehicles is not so important from a safety standpoint as the number of meetings that take place with extremely low clearances. Head-on collisions and sideswipes on 2-lane roads would not lanes when not meeting oncoming vehicles, and failed to share the width of the highway equally with oncoming drivers. The latter practice, which might be the direct cause of an accident, occurred less frequently at night on the sections of highway that were illuminated than on the unlighted sections. Each instance in which the body of a vehicle extends over the center line of the road when two vehicles meet is a potential accident maker. Fortunately, however, the one driver

TABLE 8

PERCENTAGE OF VEHICLES WITH THEIR BODIES EXTENDING TO LEFT OF CENTERLINE ON UNLIGHTED AND LIGHTED SECTIONS OF 2-LANE RURAL HIGHWAY

Group	Unlighted Highway			Lighted Highway		
	Day	Night	Difference	Day	Night	Difference
	per cent			*per cent*		
Free-moving vehicles:						
Passenger cars	5.3	5.7	0.4	4.6	8.4	3.8
Commercial vehicles	23.0	35.3	12.3	29.5	31.5	2.0
Vehicles meeting oncoming traffic:						
Passenger cars						
Meeting passenger cars	2.3	0.6	−1.7	2.3	1.0	−1.3
Meeting commercial vehicles	3.3	1.6	−1.7	3.0	0.0	−3.0
Commercial vehicles						
Meeting passenger cars	18.3	3.2	−15.1	10.2	2.2	−8.0
Meeting commercial vehicles	5.7	10.2	4.5	5.9	5.6	−0.3

TABLE 9

VEHICLES TRAVELING IN OPPOSING DIRECTIONS ON 2-LANE HIGHWAY WITH BODY CLEARANCES LESS THAN 2 FT.

Group	Unlighted Highway			Lighted Highway		
	Day	Night	Difference	Day	Night	Difference
	per cent			*per cent*		
Passenger cars meeting passenger cars	5.8	2.4	−3.4	2.7	4.9	2.2
Passenger cars meeting commercial vehicles	21.6	16.8	−4.8	14.8	19.5	4.7
Commercial vehicles meeting passenger cars	21.4	17.2	−4.2	15.2	13.2	−2.0
Commercial vehicles meeting commercial vehicles	24.0	30.8	6.8	41.4	38.8	−2.6
Commercial vehicles meeting commercial vehicles with body clearances less than 1 foot	7.4	12.1	4.7	8.8	11.1	2.3

occur if all drivers maintained the same transverse position as the average driver. Tables 8 and 9 are therefore presented to show the percentage of vehicles with drivers whose performance on the lighted and unlighted highway sections was farthest from that of the average driver in the direction that causes accidents.

Table 8 shows that a much higher percentage of the truck drivers than passenger car drivers, because of the wider units they were operating, utilized parts of both traffic yielded part of his lane to the "road hog" whenever this occurred so there were no accidents while the recording equipment was being operated.

That there were no accidents was remarkable when one considers the fact that, with an average traffic volume of 230 vehicles per hour, there was a total of 660 meetings each hour per mile of highway involving 23 meetings in which one of the drivers failed to keep his vehicle to the right of the highway center line.

Table 9 shows the percentage of meetings in which the body clearances were less than 2 ft., a value considerably lower than for average drivers. Clearances of less than 1 ft. are also shown for commercial vehicles meeting commercial vehicles, which is half the clearance that would have occurred had the drivers occupied the centers of their respective lanes. There apparently was no tendency toward fewer meetings with extremely low clearances on the lighted sections than on the unlighted sections, even though the average clearance was smaller. The difference between the daytime and nighttime values, however, was less for the lighted sections. Other extensive analyses of the clearance distributions for the various conditions failed to reveal a significantly greater uniformity in driving practices on the lighted sections than on the unlighted sections.

When drivers passed other vehicles traveling in the same direction on the lighted sections, their performance was slightly closer to daytime practices than when the maneuver was made on an unlighted section. Average body clearances with the vehicles side by side were as follows:

Light Condition	Body Clearance in feet	
	Passenger Cars Passing Passenger Cars	Commercial Vehicles Passing Commercial Vehicles
Daylight	3.3	2.3
Night—lighted	3.4	2.2
Night—unlighted	2.8	2.1

After overtaking a slower moving vehicle and awaiting an opportunity to pass, drivers have a tendency to follow too closely behind the vehicle ahead. This is an important reason that rear-end collisions occur. The number of drivers awaiting an opportunity to pass and traveling at the same speed as the vehicle ahead was approximately the same for the unlighted as for the lighted sections at night. The average time spacing between vehicles was also the same (2.1 sec., or 123ft. center to center of vehicles), but 25 per cent of the drivers who were following on the unlighted sections against 11 per cent of the drivers on the lighted sections maintained time spacings under 1 sec., a time interval insufficient for safe operation under any condition.

ACCIDENTS FOR 4-YEAR PERIOD ANALYZED

The New Jersey Highway Department supplied a very complete tabulation of the accidents that occurred during the 4-year period from 1940 through 1943 on the section of State Route 44 where the driver-behavior studies on 2-lane surfaces were conducted. A total of 126 accidents occurred between the Pennsville Ferry and the bridge at Oldmans Creek, a distance of 13.3 miles. Table 10 shows that 79 accidents, or 62.7 per cent, occurred on rural sections of the highway; 20 accidents, or 15.9 per cent, occurred within urban areas; and 27 accidents, or 21.4 per cent, occurred at important rural intersections or at the one narrow bridge. Of the total, 47 accidents, or 37.3 per cent, occurred at night, and 79, or 62.7 per cent, in the daytime.

At the time the driver-behavior studies were in progress, a log was made of the route, and comparable rural sections were selected for an analysis of accidents on the lighted and unlighted tangents. All urban sections were lighted and no two curves were identical, so accident rates with and without highway illumination could not be compared for these two conditions.

Table 11 shows the existing weather and road conditions for the 62 accidents on rural tangent sections of the highway. Table 12 shows the types of collisions that occurred. Of the accidents that took place at night, none was of a type that would be uninfluenced by light conditions. All have therefore been included in the comparison of accident rates for the lighted and unlighted tangent sections.

When analyzing accident rates, it is generally the practice to calculate the number of accidents per million vehicle-miles for day and night conditions. In this case, however, such a procedure is unnecessary when analyzing the effect of the lights, because the same traffic traveled on the lighted sections as on the unlighted sections.

The difference between the ratios obtained for the lighted and unlighted sections when the number of night accidents are divided by the number of day accidents is therefore a direct measure of the effect that the lighting had on the accident rate.

Table 13 shows that 52.9 per cent as many accidents occurred at night as during the

TABLE 10

TRAFFIC ACCIDENTS DURING 1940-1943 ON 13.3 MILE SECTION OF NEW JERSEY STATE ROUTE 44 BETWEEN PENNSVILLE FERRY AND OLDMANS CREEK

Type of Accident	Rural Sections (10.4 miles)		Urban Sections (2.9 miles)	Narrow Bridge	Intersection of S R 44 and S R 48	Entrance to Ordnance Depot	Total for Entire Highway
	Tangents	5 Curves					
Daytime							
Pedestrian:							
Killed			1	1			2
Injured	2 (3)		2 (3)				4 (6)
Motor vehicle occupant:							
Killed	1					1	2
Injured	12 (18)	5 (6)	2 (6)	1	1	2	23 (34)
Property damage only	26	7	8		3	4	48
Total	41	12	13	2	4	7	79
Nighttime							
Pedestrian:							
Killed	1		1				2
Injured							0
Motor vehicle occupant:							
Killed	3 (4)			1			4 (5)
Injured	7 (8)	3 (6)	1	3 (6)	4 (6)	2 (4)	20 (34)
Property damage only	10	2	5		2	2	21
Total	21	5	7	4	6	4	47

Note: Figures in parentheses indicate number of persons killed or injured.

TABLE 11

DISTRIBUTION OF ACCIDENTS ON TANGENT SECTIONS OF 2-LANE HIGHWAY BY ROAD AND WEATHER CONDITIONS

Road Condition	Weather	Daytime Accidents	Nighttime Accidents
		per cent	*per cent*
Dry	Clear	73.2	76.2
Wet	Rain or fog	21.9	23.8
Icy	Clear	4.9	
Total		100.0	100.0

TABLE 12

DISTRIBUTION OF ACCIDENTS ON TANGENT SECTIONS OF 2-LANE HIGHWAY BY TYPE OF ACCIDENT

Type of Accident	Daytime Accidents	Nighttime Accidents
	per cent	*per cent*
Hit pedestrian	4.9	4.8
Sideswipe going in opposite directions	12.2	23.8
Sideswipe while passing in same direction	19.5	
Side collision while entering highway or turning	24.4	23.8
Rear end collision	26.8	19.0
Ran off road	12.2	28.6
Total	100.0	100.0

TABLE 13

NUMBER OF ACCIDENTS PER 10 MILES OF RURAL 2-LANE HIGHWAY DURING A 4-YEAR PERIOD

Type of Accident	Unlighted Tangents			Lighted Tangents		
	Day	Night	Ratio of Night to Day	Day	Night	Ratio of Night to Day
	number	*number*	*per cent*	*number*	*number*	*per cent*
Fatal	1.2 (1.2)	2.4 (2.4)	200.0	9.3 (14.0)	9.3 (14.0)	100.0
Personal injury	13.3 (19.4)	8.5 (9.7)	63.8	4.7 (14.0)		0.0
Subtotal	14.5 (20.6)	10.9 (12.1)	75.1 (58.7)	14.0 (28.0)	9.3 (14.0)	66.4 (50.0)
Property damage only	26.7	10.9	40.8	18.6	4.7	25.6
Total accidents	41.2	21.8	52.9	32.6	14.0	42.9

Note: Figures in parentheses indicate persons killed or injured.

daytime on the unlighted sections. The corresponding figure for the lighted sections was 42.9 per cent. The lights, therefore, reduced nighttime accidents 18.9 per cent $\left(\frac{52.9 - 42.9}{52.9}\right)$ Accidents involving personal injuries and fatalities were reduced 11.6 per cent, and those involving property damage only were reduced 35.2 per cent by the highway lights. In terms of the number of persons killed or injured, the lights provided a reduction of 14.8 per cent. These results, although based upon a small number of accidents, do present a true picture of the conditions that existed on this highway during the past four years. By the selection of comparable lighted and unlighted sections on the same road, such factors as changes in traffic density, variations in traffic enforcement, and changes in design at the time that the lights were installed, all of which usually have a considerable effect on the results of similar studies, have been eliminated.

It cannot be emphasized too strongly that the results apply only to level tangent sections through rural locations comparatively free from intersections and other highway and surrounding conditions which tend to increase accident rates. Traffic volumes on this 2-lane highway with 8-ft. bituminous shoulders averaged approximately 3,700, 4,600, 3,100, and 3,200 vehicles per day in the years 1940 through 1943, respectively. In 1940 and 1941, approximately one-fourth of the traffic was commercial vehicles. An estimated one-third of the traffic was commercial during 1942 and 1943. Based primarily on the traffic counts at the Pennsville Ferry, it is also estimated that one-fourth of the traffic for the period 1940–1943 used the road during hours of darkness. The average accident rates for the unlighted tangent sections of the highway were therefore as follows:

Type of Accident	Accidents per Million Vehicle-miles	
	Day	Night
Fatal and personal injury....	0.36	0.81
Property damage only..	0.67	0.81
Total..............	1.03	1.62

On highway sections with such low accident rates, it would be extremely difficult to realize an appreciable reduction regardless of anything that could be done. This must be considered when evaluating the figures representing the effect of the lighting installations.

DRIVING PRACTICES ON 3-LANE HIGHWAYS NOT AFFECTED BY LIGHTS DURING LOW TRAFFIC DENSITIES

The traffic volumes on the 3-lane highways were much lower than had been expected, especially at night, during the Labor Day weekend. Under these conditions, driving practices as recorded by the speed-placement equipment were not affected at night by the highway lights.

Table 14 shows that for the same traffic density, average speeds at night were slightly higher on the lighted than on the unlighted section. However, daytime speeds were also slightly higher on the lighted section and, therefore, the higher speeds at night on the lighted section must be attributed to factors other than the difference in illumination. Eastbound traffic headed toward Atlantic City moved at an average speed consistently higher than traffic leaving the city. This is typical for locations near cities, but in this case speeds may also have been influenced by the 10-ft. bituminous shoulder provided only for eastbound traffic.

Distributions were made of the speeds, transverse placements, and longitudinal and transverse clearances between vehicles for the lighted and unlighted locations, but in no case was there any indication that the lights affected driver behavior on the tangent sections of the rural 3-lane highway. Table 15, which shows the distribution of vehicles by traffic lanes, is a typical example of the results obtained when comparisons were made for the lighted and unlighted locations.

NERVOUS TENSION TEST OF DRIVERS

While trying to develop a method to compare a driver's nervous tension on lighted and unlighted highways, the Subcommittee on Test Projects of the Committee on Highway Lighting Research considered a number of procedures including those employed by lighting experts to measure the nervous muscular tension and fatigue when reading or performing other tasks under various degrees of illumination. It was realized by the subcommittee that the problem with which they were confronted could not be solved without considerable research. The procedure that seemed to offer the most promising results, however, was a method similar to that employed by Dr. Matthew Luckiesh, Director of the General Electric Lighting Research Laboratory at Nela Park, Cleveland, Ohio, in his record correctly for subjects that move or put forth some physical effort during the test, as would be the case if applied to drivers.

The method employed by Dr. Luckiesh is based on the well known fact that nervous tension and fatigue are accompanied by a tightening of certain muscles. His technique for measuring the degree of tenseness consisted in recording the changes in muscular tension

TABLE 14
AVERAGE SPEEDS ON 3-LANE HIGHWAY

Direction of Travel	Daytime			Nighttime		
	Traffic Volume	Unlighted	Lighted	Traffic Volume	Unlighted	Lighted
Passenger cars						
	V.P.H.	M.P.H.	M.P.H.	V.P.H.	M.P.H.	M.P.H.
Eastbound	240	40.4	40.6	202	39.4	38.9
Westbound	94	34.4	37.1	120	33.1	37.1
Eastbound	70	37.8	40.0	41	36.6	38.2
Westbound	484	36.4	38.8	211	36.6	38.0
Trucks						
Total		33.6	40.1		37.4	38.7
Busses						
Total		38.5	39.6		37.8	39.5

TABLE 15
DISTRIBUTION OF VEHICLES BY TRAFFIC LANES WITH A TOTAL TRAFFIC OF 330 VEHICLES PER HOUR ON 3-LANE HIGHWAY

Traffic Lane Occupied	Daytime		Nighttime	
	Unlighted	Lighted	Unlighted	Lighted
	Percentage of vehicles			
Right-hand lane	84.2	90.6	84.4	86.6
Straddling lane line	11.5	4.8	9.5	9.9
Center or passing lane	4.3	4.6	6.1	3.5
Total	100.0	100.0	100.0	100.0
Average distance in feet from center of vehicle to right edge of pavement	6.7	6.9	6.3	6.5

very successful and well recognized measurements of fatigue and nervous tension when reading. Dr. Luckiesh has also conducted considerable research employing the electrocardiograph. He did not, however, recommend its use for the highway lighting studies because of the many difficulties involved in obtaining a record of the heart rate for a driver under actual operating conditions, and the almost impossible task of interpreting the of the fingers of the left hand which rested naturally and comfortably upon a large flat knob which was mechanically attached to an apparatus suitable for measuring the pressure exerted upon the knob. The mechanism was concealed from the subject, who was requested to press the key when turning a page while reading, but who was unaware of the fact that other pressures unknowingly exerted upon the knob were being recorded.

The same procedure could, of course, not be applied to a driver, who should have both hands on the steering wheel. For this reason it was decided by the committee, at a meeting with Dr. Luckiesh in July 1944, to develop the necessary equipment so that the same technique could be applied to a passenger in the front seat. Instead of a push button which would probably be affected by the vibration or jarring of the car, the contacts were to be operated by some sort of mechanical, hydraulic, or pneumatic pressure switch held in the passenger's right hand. It was also deemed advisable by the committee to develop equipment which would measure other factors that might be related to the nervous tension of the driver or passenger, such as changes in the driver's grip on the steering wheel, uniformity or lack of uniformity in the foot pressure on the accelerator, and changes in the driver's or passenger's pressure on the back rest of the car seat, etc.

By September 1944 when the driver-behavior studies were scheduled on the White Horse Pike in New Jersey, a number of devices in line with the committee's suggestions had been developed and mounted in a sedan. It was therefore considered advisable to make tests with this equipment on the lighted and unlighted sections in conjunction with driver-behavior studies. The primary purpose of these preliminary tests was to determine if the equipment functioned properly, and to obtain information that will be useful in developing procedures and selecting equipment when more extensive studies can be scheduled under conditions involving higher vehicle speeds and traffic densities.

Figure 3. Passenger holding rubber bulb that operates pneumatic switch.

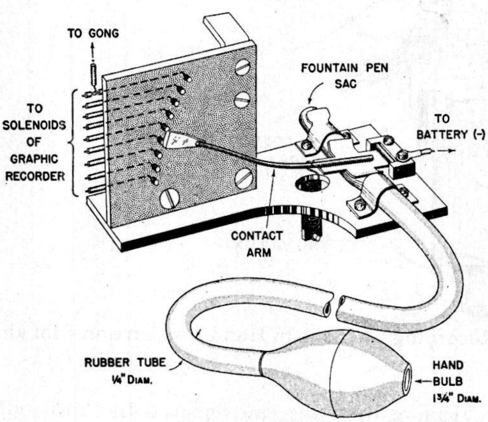

Figure 4. Device for Recording Nervous Reactions of Passenger.

The devices that had been developed and mounted in the test car were designed to measure the following items, which it was believed had a possibility of being related to nervous tension:

1. The change in pressure which the passenger exerted on a small rubber bulb held in his right hand;
2. The change in pressure on the steering wheel as caused by the grip of the driver;
3. The number of times that the direction of the pull on the steering wheel was reversed;
4. The relative pressure or changes in pressure on the back of the driver's and passenger's car seats; and
5. The movement of the accelerator pedal.

Figure 3 shows a passenger with the rubber bulb in his right hand. The tube from the bulb was connected to a pressure switch mounted in back of the front seat. To mislead the passenger as to the purpose of the bulb and to be sure that he would hold it in his hand at all times, he was told to watch the road closely and to press the bulb as quickly as possible, ringing a doorbell gong, whenever he saw a parked car, a pedestrian, or any other object except a moving vehicle on the roadway between the two lines of telephone or electric power poles which were just outside the shoulders. He was also told that the purpose of the test was to measure the distance at which he first noticed these objects.

Figure 4 shows the pneumatic switch which was connected to the hand bulb. The subjects were unaware of the fact that the switch had nine contacts, each connected to a separate solenoid operating an inked pen on a graphic time recorder. A moderate hand pressure moved the arm to the tenth contact, ringing the bell. The movement of one finger causing a slight pressure against the bulb was sufficient to change the position of the contact arm.

Figures 5 and 6 show the apparatus used to measure changes in the driver's grip on the steering wheel. Briefly, the primary parts of the apparatus consisted of a continuous rubber tube wound around the metal core of the rim; a pressure chamber and a diaphragm which operated a nest of electrical contacts mounted where the horn button normally is located; and a series of rings and spring contacts to transfer the electrical connections from the rotating wheel to a stationary cable going to solenoids operating the pens of the graphic time recorder. After removing the bakelite from the iron rim, the one piece of rubber tubing was wound spirally around the circumference of the wheel five times to avoid sharp bends which would close the opening.

At three points, each as far from the other as possible, the continuous tubing was cut and the two ends pulled over the 1-inch

The eight contacts of the switch were connected to separate insulated rings on the underside of the hub (Fig. 6C). Insulated spring contacts connected with solenoids of the graphic time recorder were mounted in the stationary cone under the hub (Fig. 6D) and were continuously in contact with the rings as the steering wheel was turned.

When the steering wheel was completely assembled with a standard cover and a sewed-in flap to cover the rubber tubing, it appeared to be a normal steering wheel, with the one exception that a doorbell button pro-

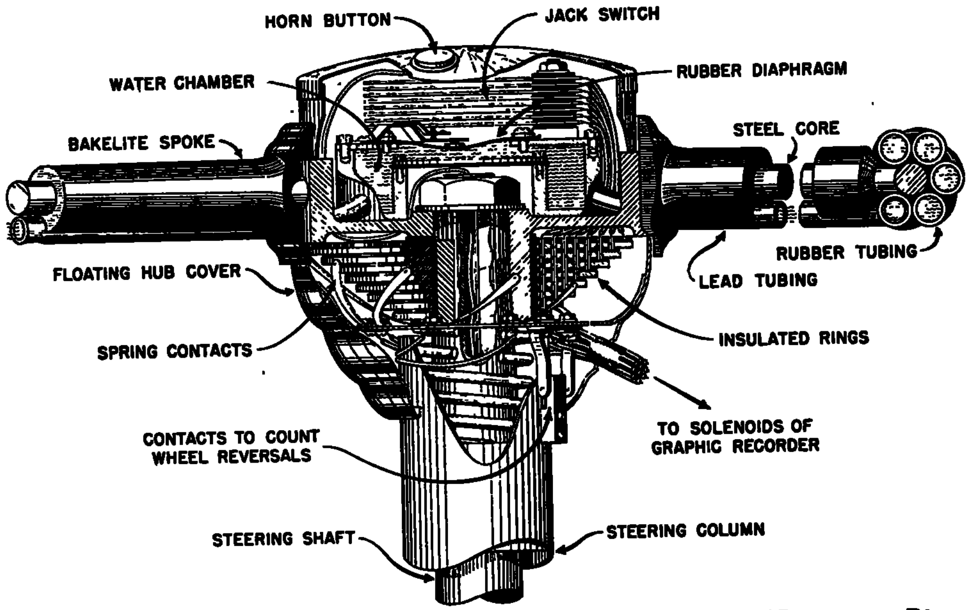

Figure 5. Steering Wheel Assembly Used for Recording Changes in Hand Pressure on Rim and Reversals of Wheel.

branches of a 3-way lead T. The other branch of the T, consisting of a ¼-in. lead tube was countersunk in the bakelite on the underside of a spoke; and connected the liquid in the rubber tubing with the pressure chamber mounted in the hub (Fig. 6C). Both the top and bottom plates of the pressure chamber were located above the burr holding the wheel to the steering shaft and therefore had to be removable and inserted after the wheel was tightened to the shaft. A rubber diaphragm, an adjustable spring contact, and an 8-contact cumulative switch were mounted on the upper cover of the pressure chamber.

truding from the cap replaced the horn button. Each test subject was informed before driving the car that the horn button which was out of order had been replaced by the doorbell button. To blow the horn, the driver pressed the palm of one hand on the horn button in the usual manner.

A driver gripping the rim of the steering wheel operated successive contacts as the grip pressure was increased until all eight contacts were closed when a moderate but very definite pressure was applied with both hands. The first contact could be easily closed by squeezing the rim between the thumb and first finger of one hand. An improvised clamp was used to apply the same pressure each time the contact arm was adjusted through a small hole in the steering wheel cap.

tirely unnecessary to keep the car on its proper course.

Reversals in the direction of pull on the steering wheel were obtained by connecting two pens of the recorders to spring contacts

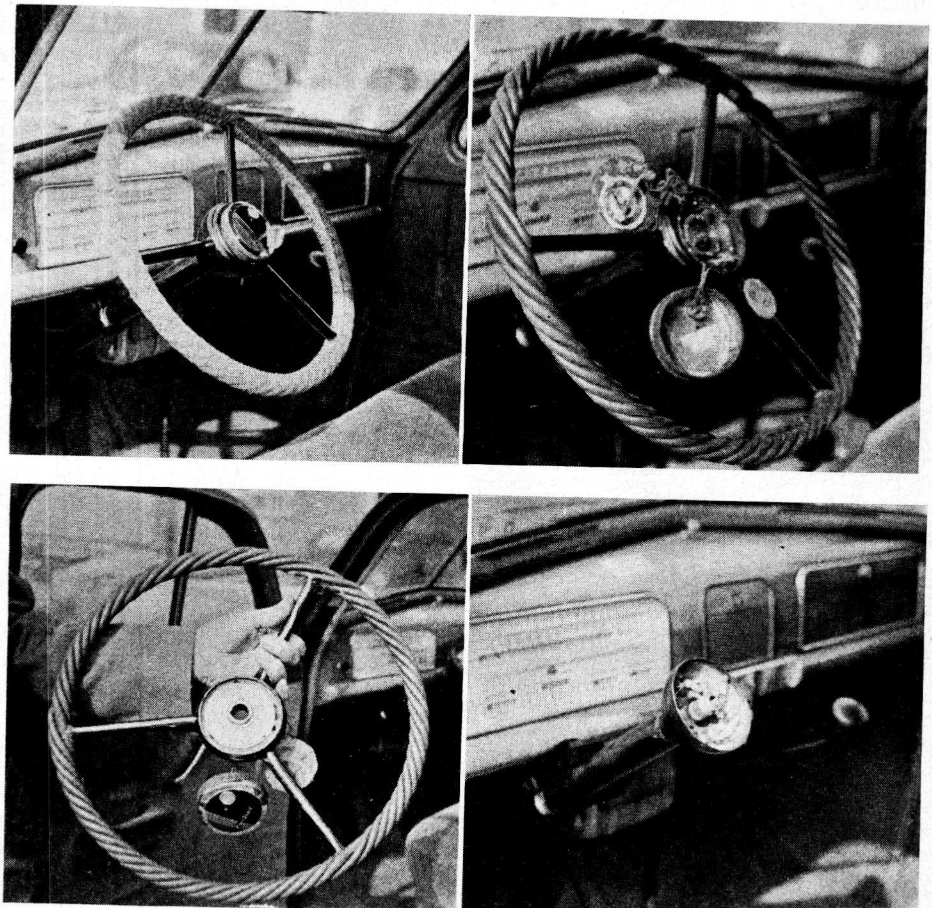

Figure 6. Steering wheel equipped with pressure device to measure changes in driver's grip.
A. (Upper left) Installed with a standard rim cover.
B. (Upper right) Rim cover, horn button plate, and top cover of pressure chamber removed.
C. (Lower left) Removed from steering column to show lead tubing on under side of spokes and contact rings on hub.
D. (Lower right) Removed from steering column to show spring contacts mounted in conical cap under the wheel.

In addition to the grip on the steering wheel, it was believed that the number of times the direction of the pull was reversed would be some indication of the driver's nervous tension. This assumes that the more nervous drivers would be continually "wabbling" the wheel back and forth at times when this was en-

mounted in the cone under the steering-wheel hub. A very slight friction between the plate in the cone and the bushing of the steering wheel was provided by the compression spring in the steering column. A "stop" on the steering column prevented the cone from rotating more than 5 deg. in either direction regardless of how far the steering wheel was turned. Each time the direction of the pull on the steering wheel was reversed, the electric circuit for one recording pen was broken and the circuit for the other pen was completed. Neither contact was made when there was no pull on the wheel or when the pull was not sufficient to turn the wheel far enough to remove most of the normal 1½-in. play in either direction.

The movement of the accelerator pedal was another operation performed by the driver that could be recorded and might provide an index of nervous tension, especially if, as a result of unfavorable driving conditions, the driver had a tendency to be changing the position of his foot on the pedal or to apply power intermittently, causing the vehicle to accelerate and decelerate frequently while

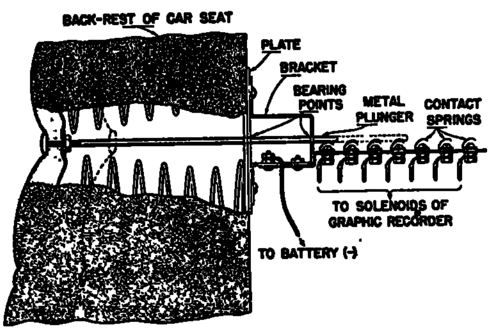

Figure 7. Device Used for Recording Changes in Pressure on Back of Car Seat.

maintaining the desired average speed. Accelerator-pedal movements on the test car were tallied automatically on the time chart by connecting six of the electrically operated recording pens to a rotary switch operated by the same levers and rods that turn the butterfly shaft of the carburetor.

Figure 7 shows the type of device used to measure the change in pressure on the cushions forming the back rests of the driver's and passenger's car seats. When either the driver or the passenger changed his position in the car seat or leaned forward while straining to see objects on the highway, the movement was recorded as a change in pressure against the back of the seat. Also any tendency of the passenger to press his feet against the floor boards was recorded by the reaction against the back of the seat.

PROCEDURE EMPLOYED IN ROAD TEST

The subjects used for the road tests were licensed drivers from Absecon, New Jersey, who thought they were volunteering for a test of their driving ability. They made the test in pairs, each acting as the driver and then as a passenger on successive runs over the test sections of highway during daylight hours and again at night. With the exception that the drivers were required to have a motor vehicle operator's license, they were not a select group and therefore probably represented a reasonable cross section of people who operate cars.

After adjusting the front seat for maximum comfort, and being told that he should drive in his usual manner maintaining an approximate speed of 35 miles per hour, the driver turned the car around and drove about half a mile before reaching the test course. He was requested not to place his hands on the spokes of the steering wheel while taking the test.

Each test run consisted of driving the car over the 5-mile course approximately half of which was lighted at night, then turning the car around and driving back to the starting point. The observer, who rode in the back seat, operated the graphic time recorders and inserted the necessary notes on the moving charts by means of a special key connected to one of the 40 recording pens. By using a predetermined code he was able to record, on the chart, the exact time that the vehicle passed objects for which the passenger had pressed the hand bulb. The code key was also pressed whenever the vehicle passed the beginning and end of the test section and intermediate stations that were used as control points. Drivers were questioned after completing the tests, but none had any idea of the location of the special devices or the type of information being recorded.

Figure 8 shows a section of two charts with the recordings made during a typical test run. The spaces between the horizontal lines represent time intervals of 1 sec., and the vertical lines indicate whether or not the electrical contact points on the various devices were open or closed. In its normal position, with the contact open, the line drawn by each pen coincides with the light line on the chart directly above the center of the pen number shown at the bottom of each chart. When

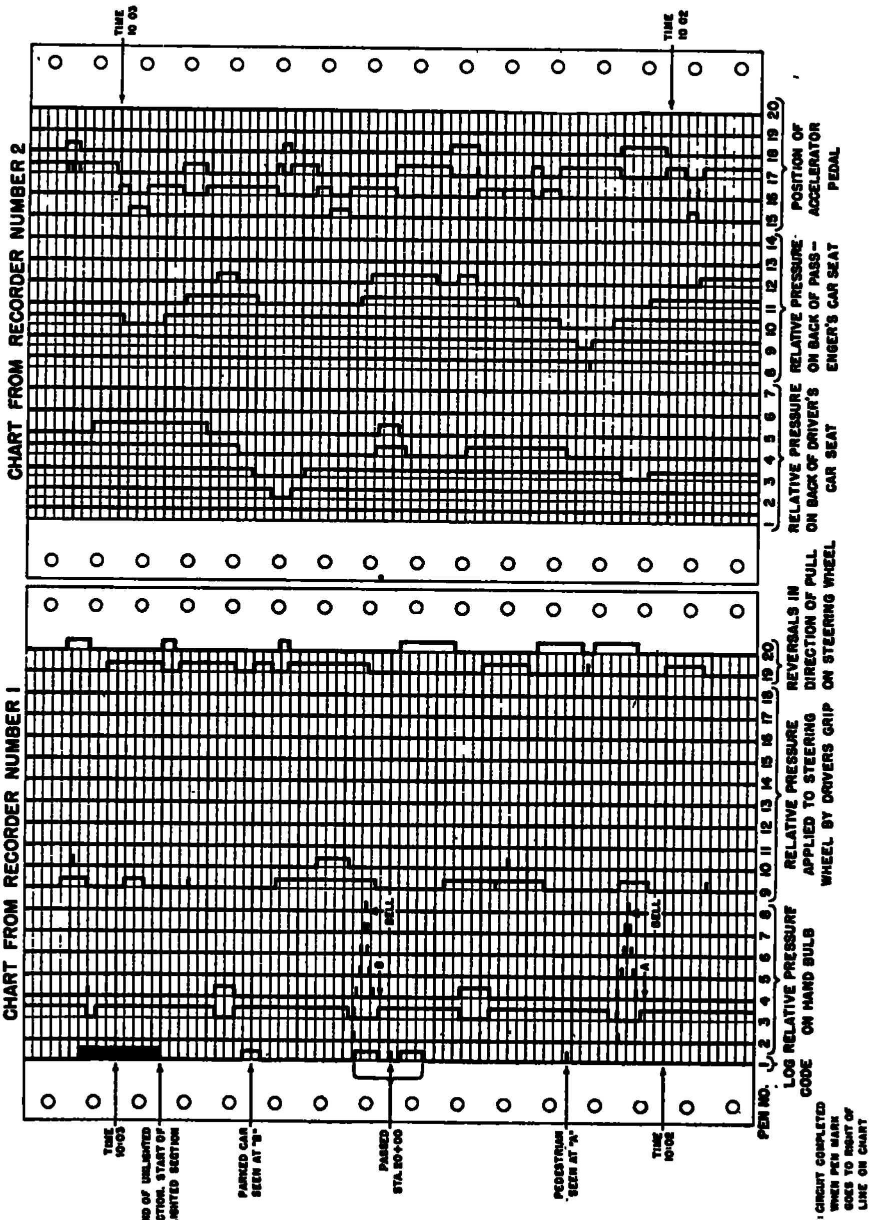

Figure 8. Typical Charts made by Graphic Time Recorders During Nervous Tension Tests.

the contact was closed, the recording pen moved slightly to the right and remained in this position until the contact was broken. For example, pens 19 and 20 of recorder number 1 show the reversals in the direction of pull on the steering wheel. From 10:01:50 to 10:01:56 (bottom of chart) the steering wheel was not being turned in either direction because both pens are in their normal position. For the next 4 sec. the contact connected to pen 19 was closed, showing that the steering wheel was being turned in the direction that would turn the front wheels of the car to the left. From 10:02:00 to 10:02:03, the steering wheel was not being turned, and then for the next 5 sec. the contact to pen 20 was closed, showing that the car was being turned to the right.

The contacts on the devices that were used to indicate the relative pressures on the steering wheel and back rests of the car seats were connected with the recording pens in such a manner that successively higher numbered pens operated and continued to operate as the pressures increased. Successively higher numbered pens also operated as the pressures on the hand bulb and accelerator increased, but the electric circuit to only one pen for each of these devices was closed at one time.

When transcribing the time charts, each movement that caused one electrical contact to be made or broken was considered as one "change," irrespective of the direction of the action. Changes caused by pressure on the hand bulb when the bell was rung to indicate the point at which an object was seen, have not been included in the totals. The travel-time between any two control points along the highway could also be obtained from marks made by the log pen, thereby supplying the necessary information to calculate the average speed on any section of the highway.

A total of 39 test runs were made between September 2 and September 6 during periods that few other vehicles were on the highway. All the volunteers were not available for both their day and night tests, so complete data for only 13 subjects who acted as drivers and passengers are available. Such a small sample is obviously inadequate as a basis for determining the effect of highway lighting on nervous tension. However, to illustrate a number of the more general findings which should be useful when designing equipment and procedures for more elaborate tests at higher speeds and greater traffic densities, Table 16 has been included. Average values for the 13 subjects while driving on tangent sections of the highway are shown.

The number of changes per mile of travel for such items as the grip on the steering wheel, movement of the steering wheel, and movement of the accelerator was generally lower at night than in the daytime, while the average pressures on the back of the seat cushion were slightly higher at night than in the daytime. This indicates that the subjects under the conditions included in these tests were not as active at night as in the daytime, or they were more at ease. The pressure on the backs of the seats, however, changed more at night than in the daytime. This may, however, have been caused by the inability of the driver to see small bumps or imperfections in the road surface as well at night as in the daytime, rather than by increased tendency on the part of the driver or passenger to be more fidgety at night.

TABLE 16
NERVOUS TENSION TESTS ON TANGENT SECTIONS OF HIGHWAY

Type of Test	Unlighted Tangent		Lighted Tangent	
	Day	Night	Day	Night
Average speed—miles per hour	36.8	38.0	37.2	38.6
Pressure exerted by passenger on hand bulb: Changes per mile of travel	0.20	0.40	0.60	0.20
Grip on steering wheel: Number of changes per mile of travel	2.65	2.75	2.50	2.00
Percentage of time that pen No. 1 operated	72.6	22.5	73.1	16.6
Steering wheel movement: Number of reversals per mile of travel	22.8	22.2	25.1	22.7
Percentage of time that wheel was turned	33.4	25.4	40.0	28.2
Pressure on back of driver's seat: Number of changes per mile of travel	4.7	9.4	7.1	7.6
Average pressure—Contact number on switch	3.54	3.68	3.58	3.68
Pressure on back of passenger's seat: Number of changes per mile of travel	2.2	3.1	1.8	2.4
Average pressure—Contact number on switch	3.34	3.54	3.48	3.47
Accelerator pedal movement: Number of changes per mile of travel	17.6	10.0	17.4	7.8

After a few test runs had been made, it was evident that the passengers were not pressing the hand bulb except when they wanted to ring the bell. In an effort to produce some reaction, the size of the bulb was changed, the contact switch was made to operate with lower pressures, and the technique was varied; but even then, it was extremely seldom that one of the passengers caused a movement of the contact arm.

Special "scare tests" were also conducted in which a passenger was taken for a ride by a special driver who performed maneuvers in a manner that no doubt frightened the passenger but which in reality were safe, having been carefully planned beforehand. The results of these tests definitely show that this bulb-grip procedure cannot be used to measure nervous tension. Even with the most sensitive device that could be employed in a moving car, it is doubtful if results of any value would be obtained. From visual observations, there appeared to be a tendency to open rather than close the fist during the scare tests.

A byproduct of the hand-bulb test was the distance at which passengers observed parked vehicles on the shoulder. The distance that black passenger cars without lights were first noticed averaged 1,364 ft. in the daytime. At night, on the lighted and unlighted sections, corresponding distances were 626 ft. and 510 ft., respectively, or an average increase of 23 per cent due to the lights. The minimum distance at night was 320 ft. on the lighted highway and 140 ft. on the unlighted highway. These values do not include the distance traveled during the passenger's reaction time which would be the time from the instant the parked car was first observed to the instant that pressure was applied to the hand bulb to ring the bell.

Too few pedestrians were seen at night to determine their comparative visibility distances on the lighted and unlighted sections of highway.

It is not possible to judge from the results obtained thus far which of the devices included in these tests will be the most satisfactory to use for obtaining a measure of nervous tension. Only by further tests during higher traffic densities and under far more extreme conditions of highway illumination including the use of headlight bulbs with low-candlepower ratings will it be possible to establish any relationships which can be used to interpret the meaning of the data recorded during this test. However, of the devices used, those recording the driver's grip on the steering wheel, and movements of the steering wheel and accelerator apparently offer the best possibilities for use in developing a criterion of nervous tension and fatigue.

It was apparent from these tests that a driver's grip on the steering wheel is much less than had been expected. The pressure was seldom sufficient to close more than one of the electrical contacts. Greater sensitivity can be obtained using the same device; but this may not be desirable when conducting tests at higher speeds, or during heavier traffic densities, or on a highway with more curves. Under these conditions, a driver's grip on the wheel can be expected to be greater than while traveling less than 40 miles per hour on a level tangent section of rural highway practically free of other traffic.

The operation of the equipment used to record the various items included in this test was, in general, very satisfactory. It was fortunate, however, that the original idea of connecting each of the contacts to a separate cumulative counter to obtain the number of changes was discarded in favor of the recording pens. If cumulative counters had been employed it would have been impossible to eliminate the counts caused by sparks jumping between the contacts immediately before the gap was completely closed. By employing the charts and the recording pens, marks such as those near the top of the line made by pen 17 of recorder number 2 in Figure 8, which were caused by sparking, could be identified and eliminated when the record was transcribed. It was also possible to correlate changes in the various items with each other and with influencing factors such as the highway alinement, and traffic conditions.

The use of recording galvonometers and variable resistance switches in place of the 20-pen recorders and contact switches would be a further improvement that should be considered when additional studies on nervous tension are conducted. Sparking would then be eliminated and the record would show smaller pressure changes for the same range than can possibly be recorded with six to eight contacts for each item.

SUMMARY OF RESULTS AND CONCLUSIONS

It should be borne in mind when interpreting the significance of the results of this study that the investigations were confined to tangent sections on rural highways where there were few pedestrians and property entrances; that the traffic densities were comparatively low; and that the lighting installations were not of the most modern design although of the predominate type used for highway lighting during recent years.

When qualified by these considerations, the results of this study may be summarized by the following statements:

1. Highway lighting does not affect travel speeds.

2. Based on transverse positions and clearances between vehicles, the behavior of drivers at night conforms more nearly to their daytime practices when the highway is lighted than when the highway is unlighted. The difference, however, is slight.

3. Certain driving practices at night which tend to cause accidents are reduced a measurable amount by providing highway illumination. This is verified by the actual accident rate as well as by the potential accident hazard as determined by the driver-behavior studies. The driving practices that seem to be directly affected are: (1) the tendency of drivers to follow too closely behind a preceding vehicle traveling at the same speed, and (2) failure of drivers to keep their vehicles to the right of the center line when meeting other vehicles on a 2-lane highway.

4. With the exception of the hand bulb, the devices used in an attempt to measure nervous tension recorded the desired data; but the significance of the difference between the average values recorded for the lighted and unlighted highway sections cannot be evaluated without further research. It is questionable whether the absence of nervous tension is conducive to safety or whether a certain amount of nervous tension is an accident-preventing factor. The optimum between "comfort" and "safety" must be established before the data can be properly interpreted.

The results of these studies do not present sufficient evidence to prove that continuous lighting on main rural highways of reasonably modern design including long tangent sections can be justified. When considered in conjunction with the reported findings of other investigations, it is evident that for the same expenditure a much greater benefit can be realized by lighting sections through urban areas and hazardous locations such as sharp curves and important intersections.

Extensive research will be required to develop a device or combination of devices that will measure some factor which is directly related to a driver's nervous tension and to establish a reliable correlation that can be used in evaluating whatever intangible benefits may be derived from highway lighting. Such a device or combination of devices when developed will be extremely useful in connection with numerous other highway design and traffic control problems.