Effect of Pavement Edge Markings on Operator Behavior

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● TWENTY YEARS AGO the Connecticut State Highway Department applied paint markings along the outer edges of the travel portion of roadway to delineate the separation point between paved roadway and paved shoulder. This application was made on a 2-lane highway which carried substantially heavy traffic volumes and was used by many pedestrians. The pedestrians were mostly residents from a Veterans Home who walked along this highway frequently between the home and a village located some 3 mi distant. (Numerous accidents had occurred during hours of darkness, many of them fatal, involving vehicles and pedestrian.) The placing of a continuous white stripe along the outer edge of pavement provided an area for these pedestrians to walk and at the same time delineated the limits of the traveled roadway for operators of motor vehicles. These lines were termed shoulder lines and their effectiveness was measured by the elimination of pedestrian accidents at night and significant favorable public response to "shoulder striping."

The intent of the foregoing statement is to present the background for Connecticut's edge-marking policy which during the past years has expanded from 3 mi of shoulder striping to a program which now involves painted edge markings on nearly 1,500 mi of roadway. Subsequent to the favorable public response following the initial installation of edge markings or "shoulder lines," several selected locations were marked similarly. These later markings were still termed "shoulder lines" and intended to provide a refuge area for children walking to and from school in rural areas, along roads carrying comparatively large traffic volumes at relatively high speeds. There is no accident experience to accurately measure statistical benefits at these locations but it can be demonstrated through vehicle placement and speed measurements at specific study points that vehicular traffic was influenced by the presence of a painted edge line and that the roadway appeared to be safer particularly for the pedestrians required to use the shoulder.

Following the application of edge lines on several miles of 2-lane roads it was suggested to the Department that the outer edge or curb of the Merritt Parkway be painted to provide a safer nighttime travel condition; it was the opinion that painted curbings would furnish drivers with improved pavement delineation during inclement weather or fog conditions. The 38 mi of Merritt Parkway was edge striped in 1954 but not until a study was completed at a test section to determine what, if any, influence a paint stripe along the outer edge of the parkway would have on operator behavior. The results of this study are explained as part of this paper.

The Connecticut Highway Department now stripes the outer edges of all

4- or 6-lane divided roadways and a high percentage of the 2-lane road system. Since 1956 the Department has used yellow paint for the edge striping on these 2-lane and multilane facilities. Yellow was selected as it is in contrast to the continuous white centerline used in a barrier system to denote "No Passing Zones" on 2-lane roads, and on the inside edges of the median divider where continuous white line is applied. No

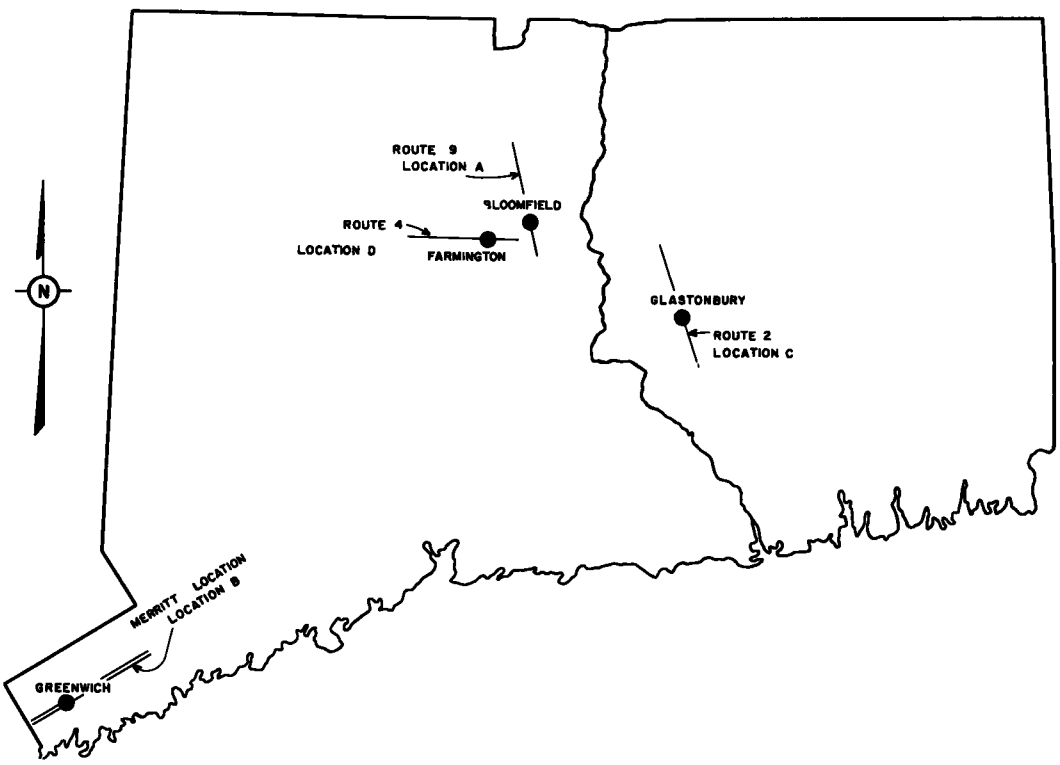


Figure 1. Study location sites.

studies have been made to measure what possible differences in operator performance may occur with the use of yellow edge lines as compared with white.

The expansion of Connecticut's edge marking from its initial shoulder line application to its present 1,500 mi of edge striping has not been based upon favorable public reaction alone. It is also supported by the results of studies conducted at several locations on state highways where changes in operator behavior and vehicle operation and performance have been observed after edge lines were applied. The purpose of this paper is to describe the methods used in these studies together with the observations and conclusions derived therefrom.

LOCATIONS FOR STUDY

The locations where studies have been performed are described as fol-

lows: Figure 1—Bloomfield, Route 9; Meritt Parkway, Greenwich; Glastonbury, Route 2; Farmington, Route 4.

Location A—Figure 2

Route 9 in Bloomfield was studied before and after edge marking were placed as the result of requests to provide protection for school children. These observations were made in 1950 and again in 1951. This is a section of highway carrying ADT of 3,400 vehicles. The road originally constructed as an 18-ft bituminous penetration with 5-ft shoulders was later surface treated the full width of 28 ft with no discernible shoulder areas. Sparsely placed homes along the route make it residential and a generator of light pedestrian volumes, where during certain times of the day concentrations of children walking to and from school may be observed. To provide some sort of refuge area for this movement, continuous white lines were painted along the outer edges of a 20-ft traveled portion of roadway.

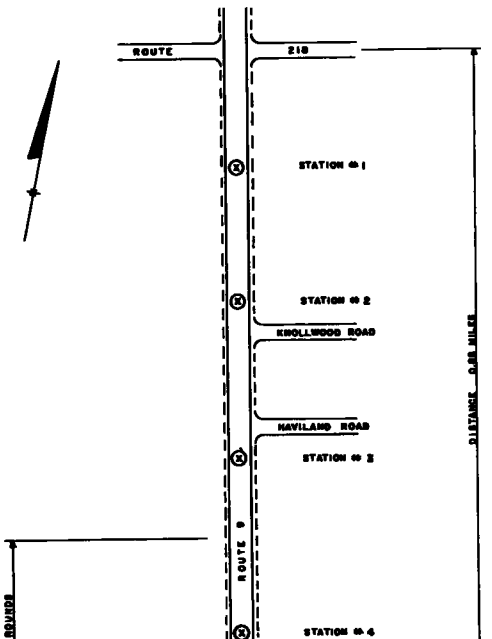


Figure 2. Location A.

Location B—Figure 3

The Merritt Parkway was a limited study to determine any influence on driver behavior after edge lines were placed on a 4-lane divided highway. This is a tangent and curve on the eastbound lanes of the Merritt Parkway. The study site chosen was on a bituminous concrete section of the Merritt Parkway located in the town of Greenwich. It is a tangent curve area and measures 2,000 ft in length, it encompasses a 40-deg 30-min left-hand curve which, in itself is 1,554 ft long. Other physical features which enhanced the particular location as a study site were the descending grade through the test area, the presence of a wire rope railing in the first section of the area, planting in the esplanade, and a tangent area leading to the curve, of sufficient length to establish base speed and transverse placement values. The bituminous concrete pavement measures 26 ft wide and the outer shoulder area adjoining, constructed of a like surface, averages 8 ft wide. Gradient for eastbound vehicles varies from -5 percent at Station No. 1 to -1.6 percent at Station No. 2, to -3.8 percent at Station No. 3. Sight distances are to be considered unlimited (more than 500 ft) except in the region of Station No. 2 where this distance falls only slightly, to 450± ft.

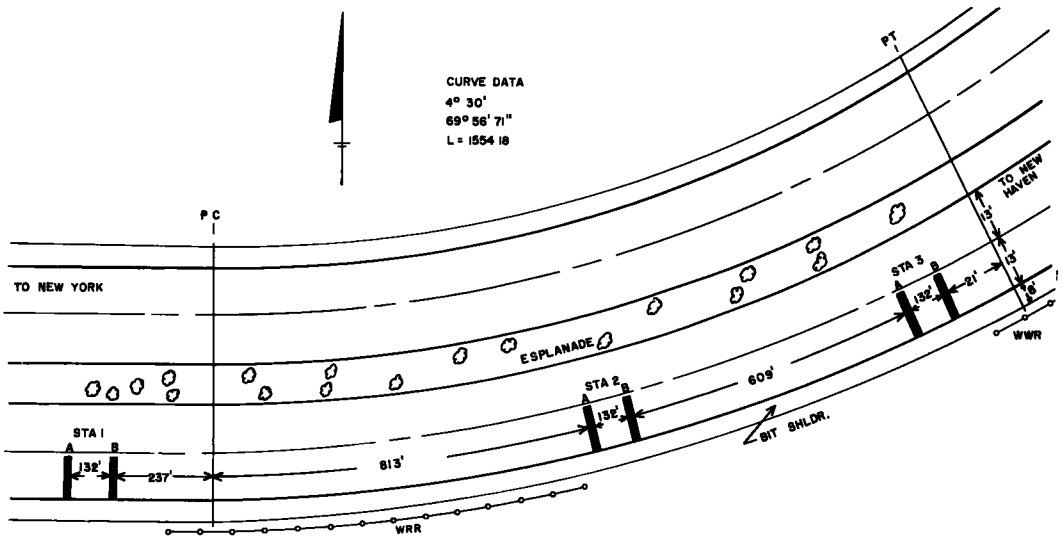


Figure 3. Test area—Town of Greenwich, Route 15, Location B.

Location C—Figure 4

The Glastonbury, Route 2 study was made on a newly constructed section of 2-lane roadway with black top surface and paved black shoulders. The study was done in cooperation with a student at the Yale Traffic Bureau, an employee of the highway department, as a thesis project. Route 2 in the study area is a 2-lane rural highway running in a general northeast-southwesterly direction and carrying an annual ADT volume of 5,300 vehicles (1953). The roadway was reconstructed on new alignment and grade in 1949 with a 24-ft armor-type surface and 8-ft bituminous surfaced shoulders providing a total paved width of 40 ft. The pavement is divided into two 12-ft lanes by a painted white dashed centerline (reflectorized). Both pavement and shoulders were in excellent condition and were discerni-

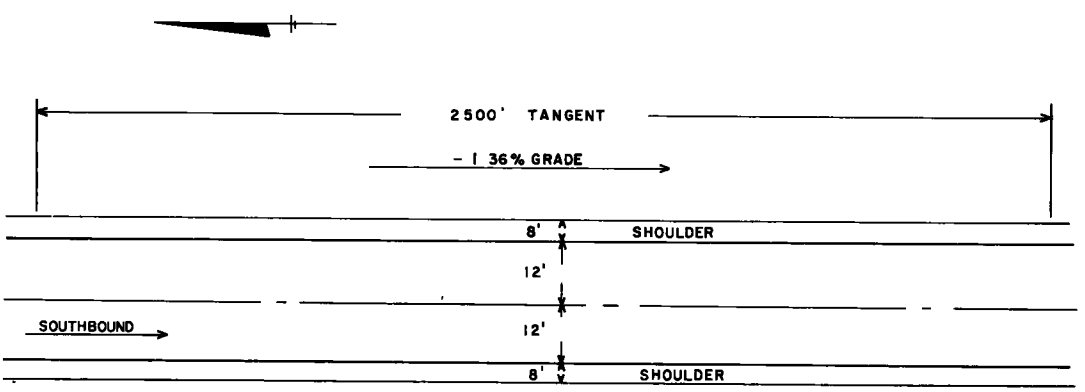


Figure 4. Test area—Town of Glastonbury, Route 2, Location C.

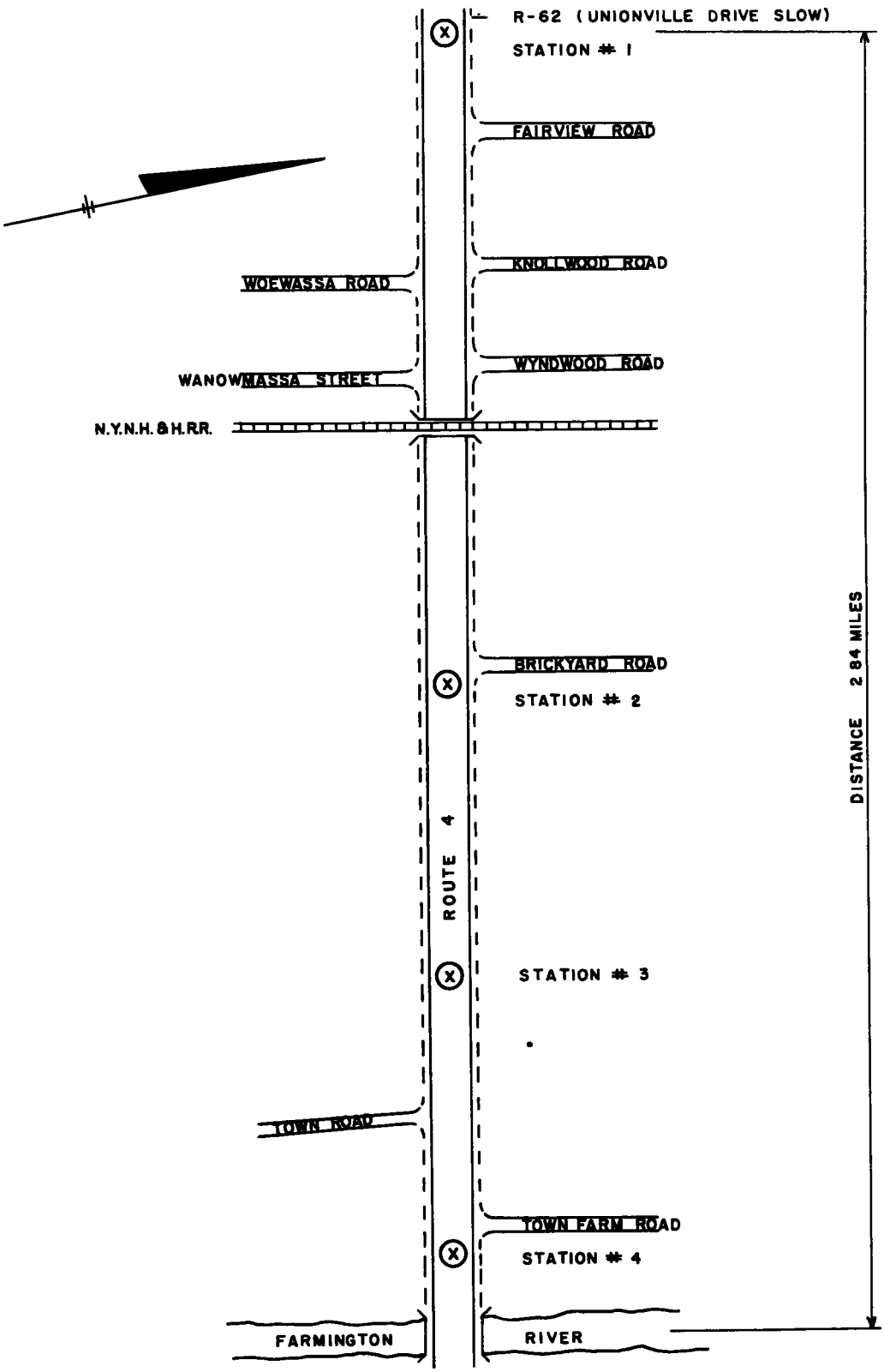


Figure 5. Location D.

ble, one from the other, during daylight hours. The study site was confined to the southbound lane only. The site lies roughly in the center of a 2,500-ft tangent with a minus 1.36 percent gradient (southbound) extending at least 700 ft either side of the site.

Location D—Figure 5

The Farmington, Route 4 studies were made at 4 locations in this area. Observations of traffic performance were made before any pavement markings were placed, with centerline striping and with both centerline and edge markings. This is a rural area sparsely developed as residential and business. Some pedestrian traffic is present on the shoulder areas with many being children walking to and from school. Vehicular traffic averages 5,000 vehicles per day. Route 4 is a black top pavement with bituminous surfaced shoulders matching the paved surface to give an appearance of the wide roadway with no shoulders. The test areas selected are not all similar in cross-section, thus offering an opportunity to augment the effectiveness of pavement markings on a highway with variances in roadway width and cross slope. A physical description of each of the 4 study areas is as follows:

Station #1.—24 ft . . . bituminous-treated travelway; 1.5 ft . . . bituminous-treated shoulders; 12 ft . . . distance between center stripe and shoulder stripe; and 1/8 in. per ft . . . cross slope.

Station #2.—28 ft . . . bituminous-treated travelway; 3 ft . . . bituminous-treated shoulders; 13 ft . . . distance between center stripe and shoulder stripe; and 1/4 in. per ft . . . cross slope.

Station #3.—30 ft . . . bituminous-treated travelway; 4 ft . . . bituminous-treated shoulders; 13 ft . . . distance between center stripe and shoulder stripe; and 1 in. per ft . . . cross slope.

Station #4.—24 ft . . . bituminous-macadam travelway; 8 ft . . . bituminous-treated shoulders; 14 ft . . . distance between center stripe and shoulder stripe; and 1/8 in. per ft . . . cross slope.

TABLE 1

AVERAGE SPEEDS (MPH)

Speed Observations	Sta. 1	Sta. 2	Sta. 3
Day			
1. Before shoulder line installed	55.7	56.5	54.3
2. After line—18 in. off edge of pavement	54.9	54.2	51.2
3. After line—at edge of pavement	52.9	50.8	53.1
Night			
1. Before shoulder line installed	52.1	47.8	48.5
2. After line—18 in. off edge of pavement	53.8	51.6	53.8
3. After line—at edge of pavement	51.6	51.0	53.0

METHODS USED IN STUDIES

Location A involved the measurement of transverse placement alone and was accomplished by placing chalk lines transversely on the travel lanes and positions coded at 1-ft intervals starting at the painted centerline and measuring outward. The left wheels of vehicles were observed and their positions recorded so that a distribution of vehicle lateral placement was obtained.

Location B involved the measurement of transverse placement and speed. Equipment used was an Easterline-Angus battery-operated 20 pen recorder with rubber coated pressure-sensitive detector tapes placed on the pavement and connected with the recorder by means of multi-wire transmitting cable. Observations were recorded at three locations:

Station #1—237 ft west of the P.C.
Station #2—813 ft east of the P.C. (52 percent around curve)
Station #3— 21 ft west of the P.T.

The detectors consist of 10 ea. 12-in. long segments with 2-2½-in. terminal area at either end. Approximately the center 8 in. of each segment is sensitive to pressure and on actuation transmits an impulse to the corresponding pen of the recorder. Placement of the detectors on the outer lane at right angles to the centerline and with the zero end of tape at the outer edge of pavement permits accurate transverse placement recordings. By spacing two tapes 132 ft apart at each station and adjusting the recording paper to turn at 10 graduations per second it was possible to obtain the placement and speed of a vehicle at each station. Because the speed tape placed in advance of the placement tape was, in effect, a duplicate piece of equipment, the total recordings for one vehicle through each station consisted of two transverse placements and one speed rating.

ANALYSIS OF DATA

At Location A transverse placement of vehicles was observed in November 1950 with a painted white centerline and no edge markings. Measurements were again taken in October 1951 after the edge markings had been added and were in place approximately 10 months. Between 600-700 vehicles were observed prior to the edge striping and approximately the same number afterwards. Vehicles observed here were all free-moving and not influenced by opposing traffic. Nonuniformity in the pavement cross-section and slight variance in the over-all width of paved surface apparently influenced vehicle placement so that no distinct pattern is discernible. However, the comparison before-and-after studies reveal a change in the vehicle performance from the original observations (Figs. 6, 7, 8 and 9).

At Location B the lateral placement and speed observations totalling 11,289 were obtained at six locations. Observations were limited to free-moving vehicles in the outer lane first, because speed and placement of the vehicle in question might be affected by the presence of a second vehicle in the proximity and, second, because it was presumed there would be no effect of a right-hand shoulder line on traffic moving in the second lane (Table 1).

Figure 10 shows that in the daytime vehicles are positioned closer to the center of lane when the 4-in. white line was painted 18 in. away from the edge of shoulder. At night, vehicles traveled nearer to the lane line with the line painted at the edge of pavement.

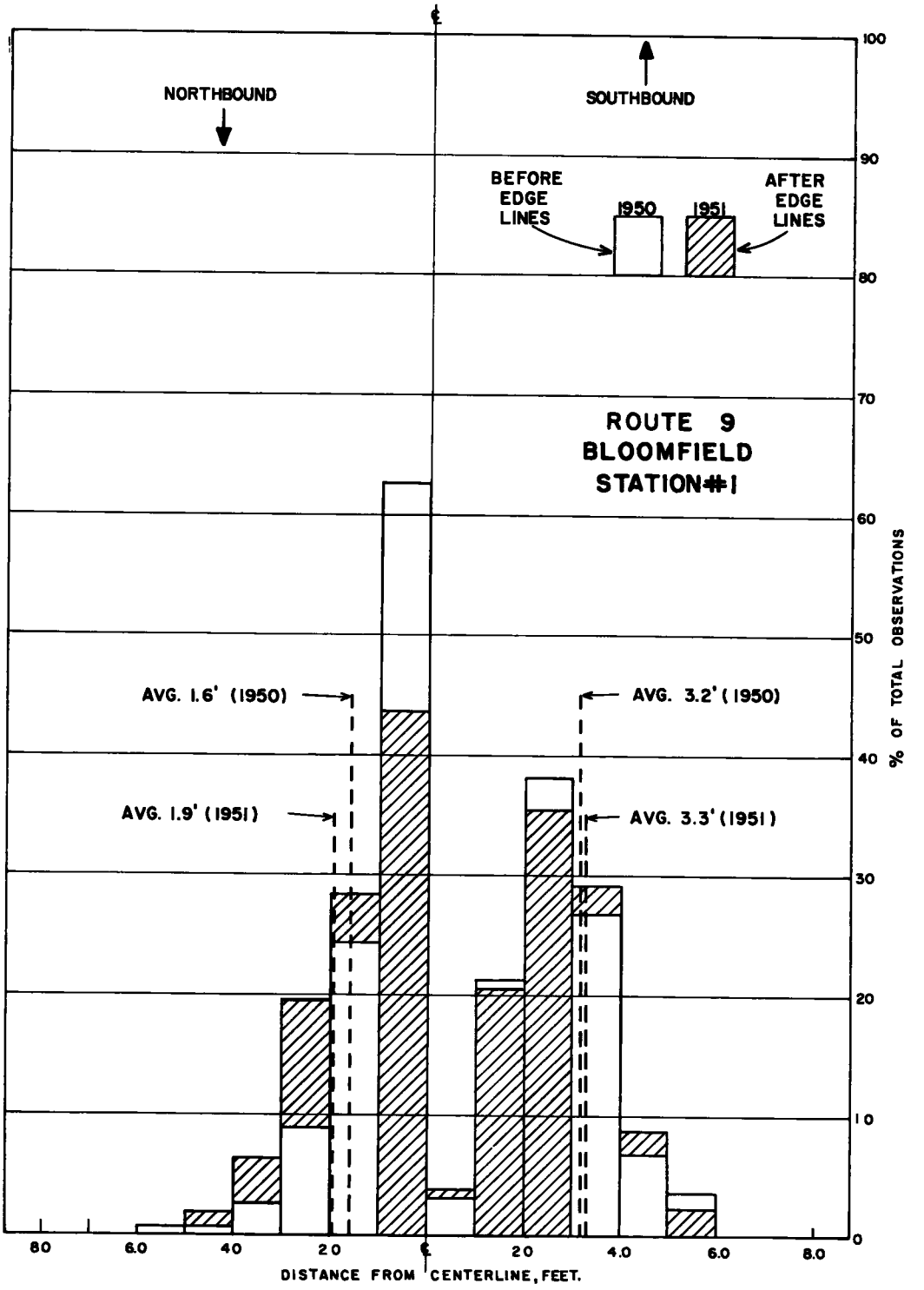
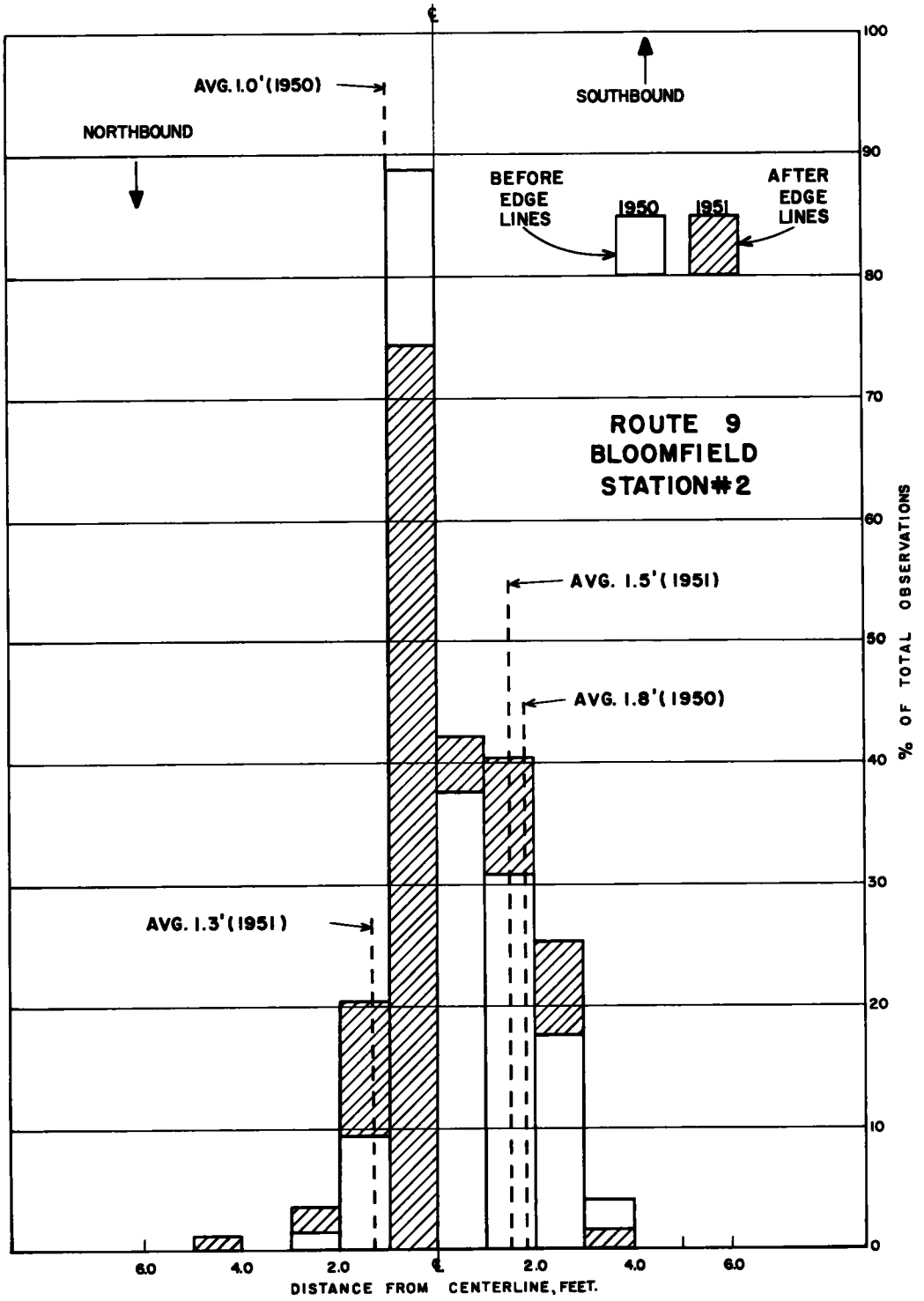

NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION #1
AVG. 1.6' (1950)
AVG. 3.2' (1950)
AVG. 1.9' (1951)
AVG. 3.3' (1951)
% OF TOTAL OBSERVATIONS
100
90
80
70
60
50
40
30
20
10
0
8.0
6.0
4.0
2.0
2.0
4.0
6.0
8.0
DISTANCE FROM CENTERLINE, FEET.

Figure 6.


℄
AVG. 1.0'(1950)
NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION#2
AVG. 1.5'(1951)
AVG. 1.8'(1950)
AVG. 1.3'(1951)
100
90
80
70
60
50
40
30
20
10
0
% OF TOTAL OBSERVATIONS
6.0
4.0
2.0
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2.0
4.0
6.0
DISTANCE FROM CENTERLINE, FEET.

Figure 7.

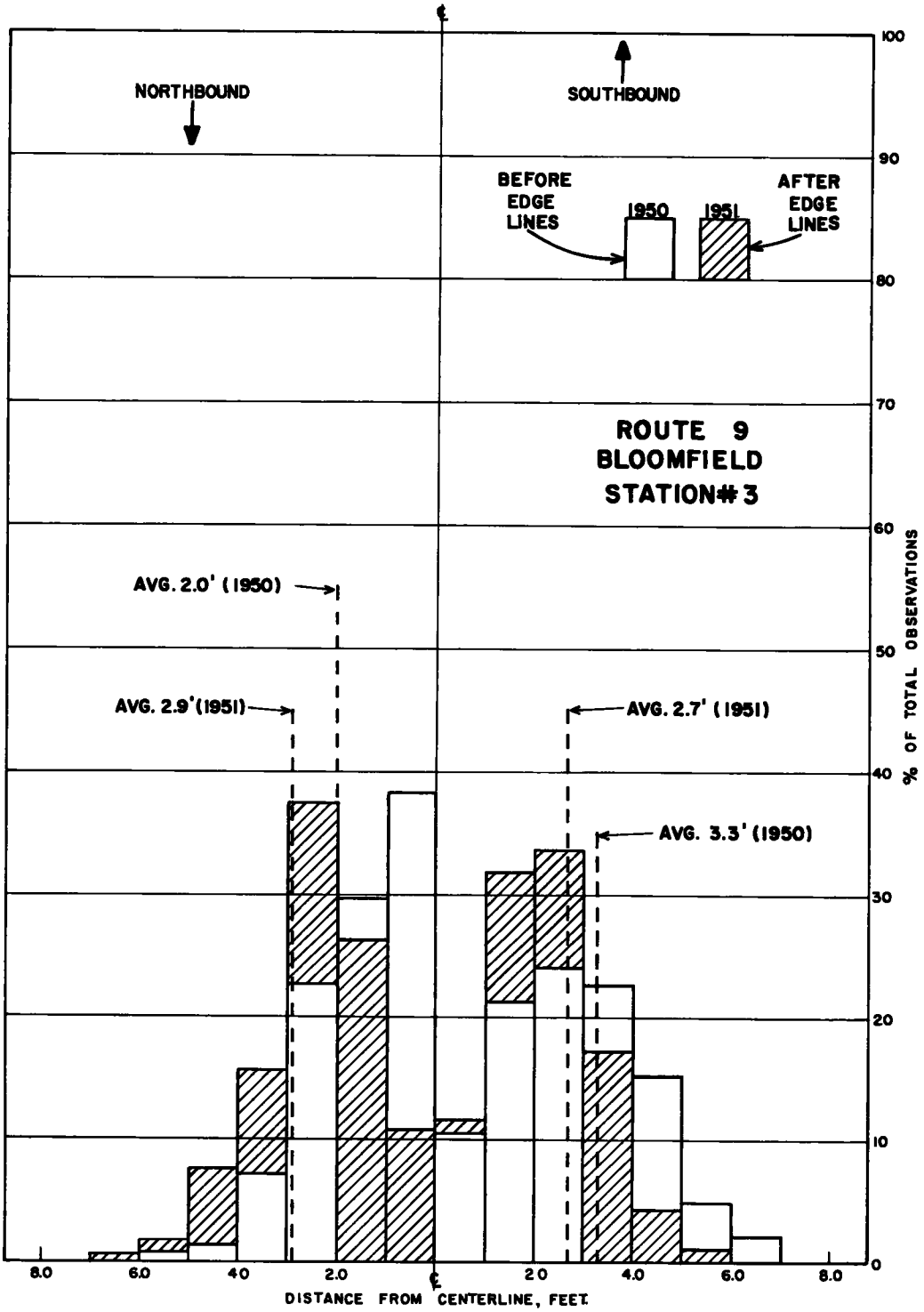
NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION#3
AVG. 2.0' (1950)
AVG. 2.9'(1951)
AVG. 2.7' (1951)
AVG. 3.3' (1950)
% OF TOTAL OBSERVATIONS
100
90
80
70
60
50
40
30
20
10
0
8.0
6.0
4.0
2.0
2.0
4.0
6.0
8.0
DISTANCE FROM CENTERLINE, FEET

Figure 8.

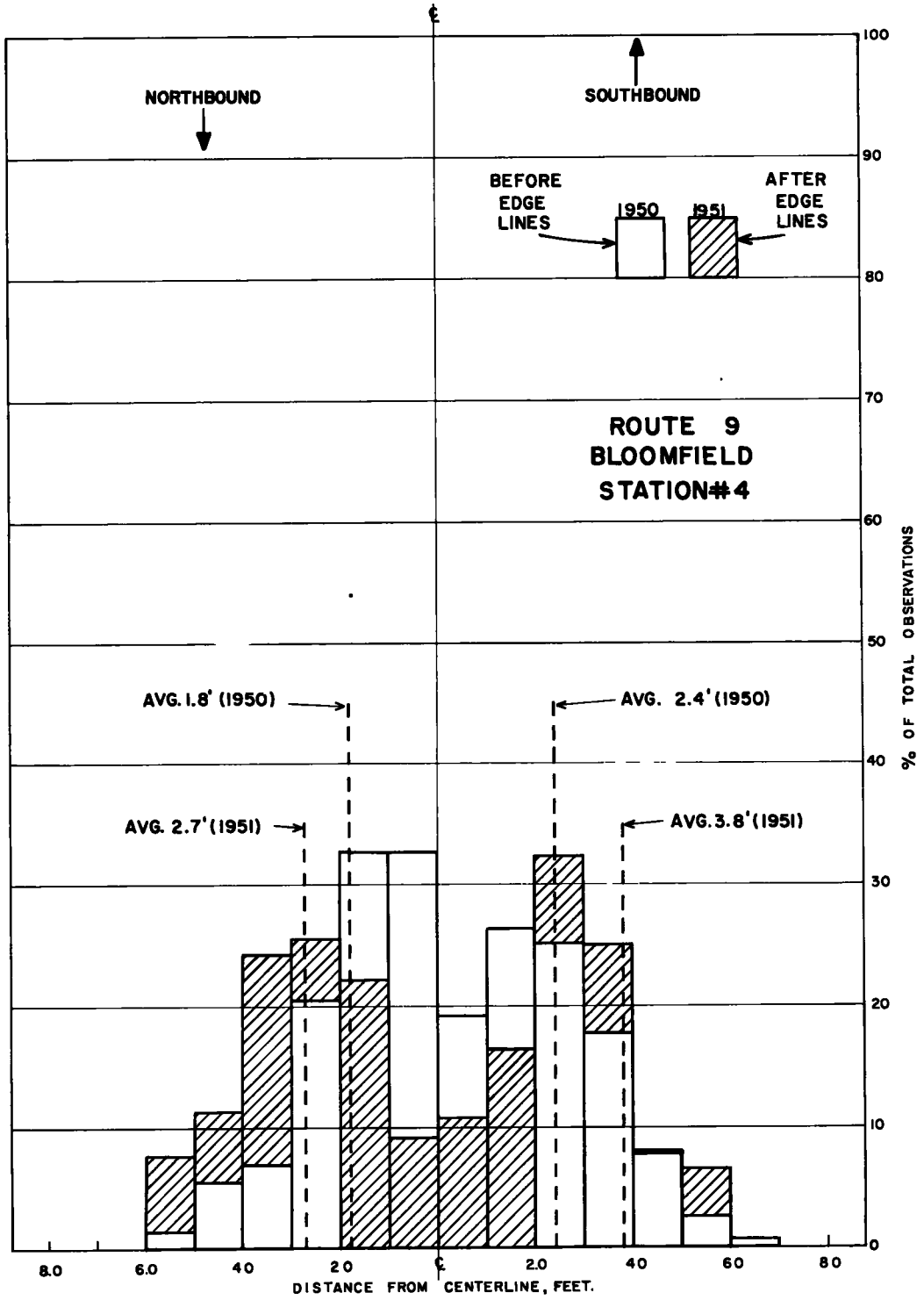
℄
NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION#4
AVG. 1.8' (1950)
AVG. 2.4' (1950)
AVG. 2.7' (1951)
AVG. 3.8' (1951)
100
90
80
70
60
50
40
30
20
10
0
% OF TOTAL OBSERVATIONS
8.0
6.0
4.0
2.0
℄
2.0
4.0
6.0
8.0
DISTANCE FROM CENTERLINE, FEET.

Figure 9.

TABLE 2

SUMMARY—AVERAGE LATERAL POSITIONS [a]

Time	Condition	Number Samples Obtained	Mean Position (ft)
Day	Before	297	3.73
Day	After	231	3.85
Night	Before	172	2.28
Night	After	162	2.69

[a] Distance in feet from centerline of road to left wheel of vehicle.

Figure 11 shows that during the daytime, with no edge stripe, vehicle speeds rose slightly between the beginning and middle of curve and then dropped sharply on reaching the end of curve.

At night the speeds dropped 4 mph between the beginning of curve to middle of curve and rose slightly from this point to end of curve.

With a 4-in. line 18 in. outside of the pavement edge in the daytime vehicle speeds dropped slightly between beginning and middle of curve and

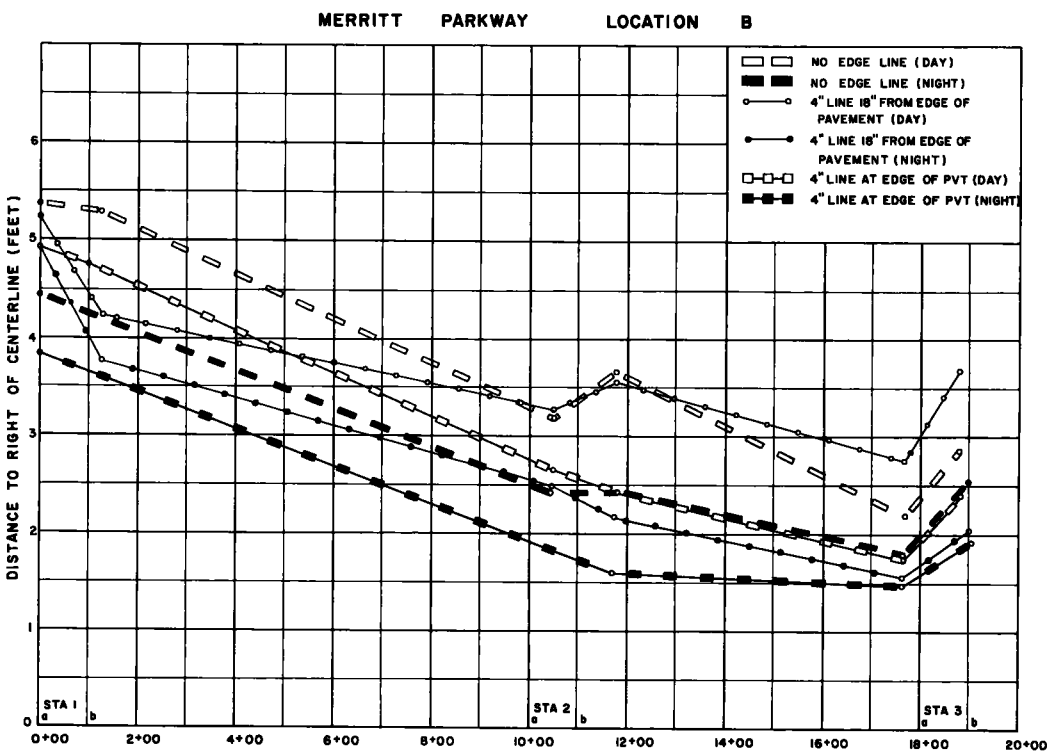

Figure 10.

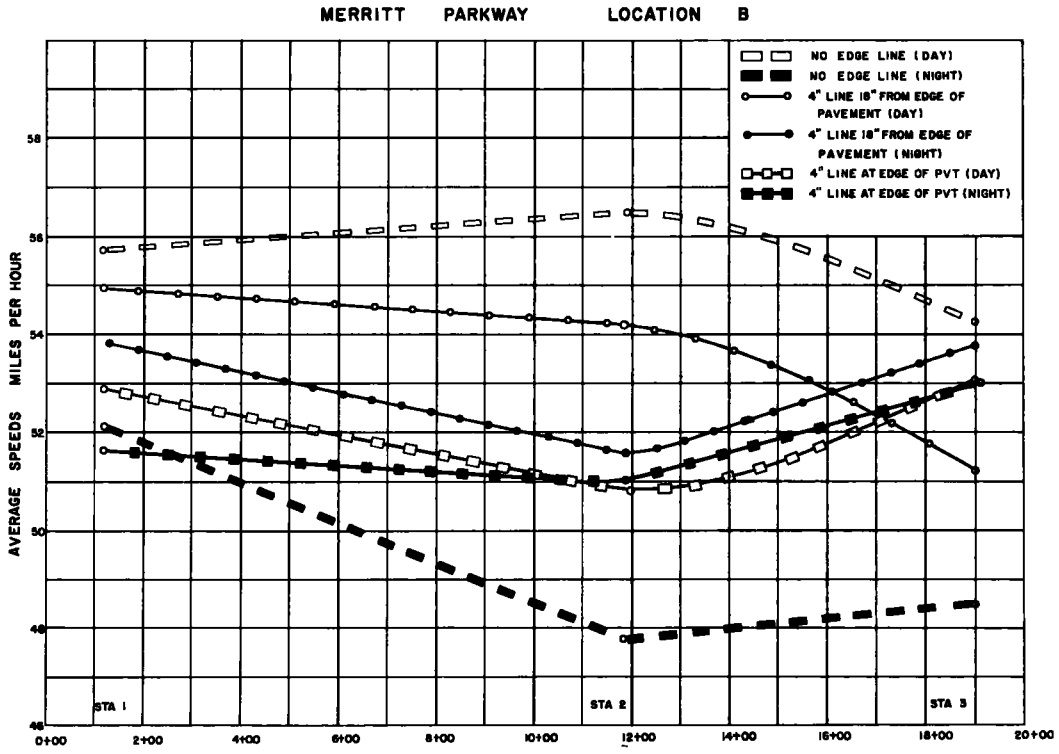

Figure 11.

then lowered abruptly to the end of curve. At night the speeds dropped sharply from beginning to middle of curve and then rose towards the end of curve.

With the edge line at edge of pavement during both day and night operation speeds lowered slightly from beginning of curve to the mid-point and then rose slightly to the end of curve.

It appears that a more uniform movement occurred when a 4-in. line was painted on the pavement's edge.

TABLE 3

SUMMARY—SPOT SPEEDS

Time	Condition	Number Samples Obtained	Mean Speed (mph)	85% Speed (mph)
Day	Before	277	47.7	51.8
Day	After	230	51.8	55.2
Night	Before	172	43.6	48.5
Night	After	161	50.1	54.7

A comparison of average lateral positions under the various conditions of the study at Location C are given in Table 2. After installation of the pavement edge line, the changes in the average lateral position of vehicles are noted as follows:

Daytime—a shift of 0.12 ft to the right, away from the centerline or, toward the edge of line.

At night—a shift of 0.41 ft to the right, away from the centerline toward the edge line.

A comparison of daytime with nighttime average lateral positions reveals the following:

Before edge line—night positions are 1.45 ft nearer to the road centerline than day positions.

After edge line—night positions are 1.16 ft nearer to the road centerline than day positions.

Spot Speed—Analysis

A tabular comparison of spot speeds irrespective of lateral position is given in Table 3.

From Table 3, it is apparent that after the installation of the pavement edge lines, the daytime average speed increased 4.1 mph and the nighttime average speed increased 6.5 mph.

Average speeds at night were consistently less than daytime average speeds; however, after painting of the pavement edge line, the speed differential between night and day speeds was reduced from 4.1 to 1.7 mph.

When the after studies were started, edge markings had been placed using yellow reflectorized paint.

At Location D where 4 separate conditions were studied, vehicle placement was first observed with no pavement markings. Vehicle placement was again observed after the application of a white reflectorized centerline. A third observation was made after the addition of a continuous 4-in. yellow reflectorized shoulder line.

The study was undertaken on weekdays from October 28, 1957, through December 31, 1957, from 12: Noon to 8:00 P.M. Vehicle placement was observed for one direction only, with no differentiation between vehicle types. The only two vehicle maneuvers considered were free-moving and meeting opposing traffic. Average values of the transverse placement are shown in Figures 10, 11, 12 and 13.

These Figures indicate the following trends:

1. With or without pavement markings, both free-moving vehicles and vehicles meeting opposing traffic tend to travel closer to the known centerline at night than during daylight hours.
2. The transverse placement of vehicles on a road with centerline and edge marking varies with the positioning of the shoulder line.
3. The vehicle placement of a centerline marked highway is closer to the known centerline than on a similar unmarked highway.
4. The addition of an edge line to the centerline has little effect during the day; however, at night this additional edge marking tends to position free-moving vehicles more centrally in the marked lane.
5. The positioning of vehicles with opposing traffic showed little change except on the widest section of roadway where the position away from the centerline at night indicated the greatest variance.

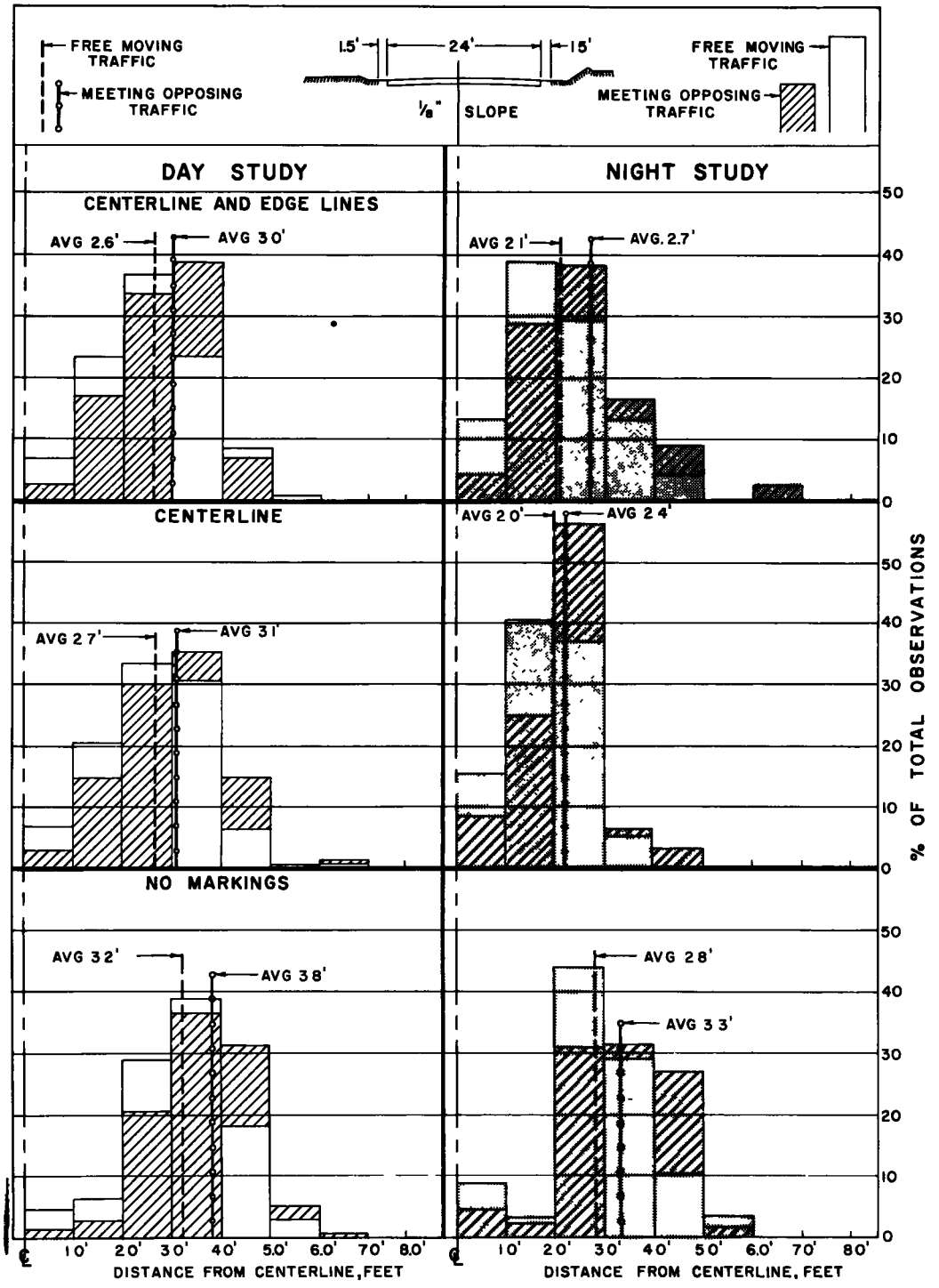

Figure 12. Farmington Station #1.

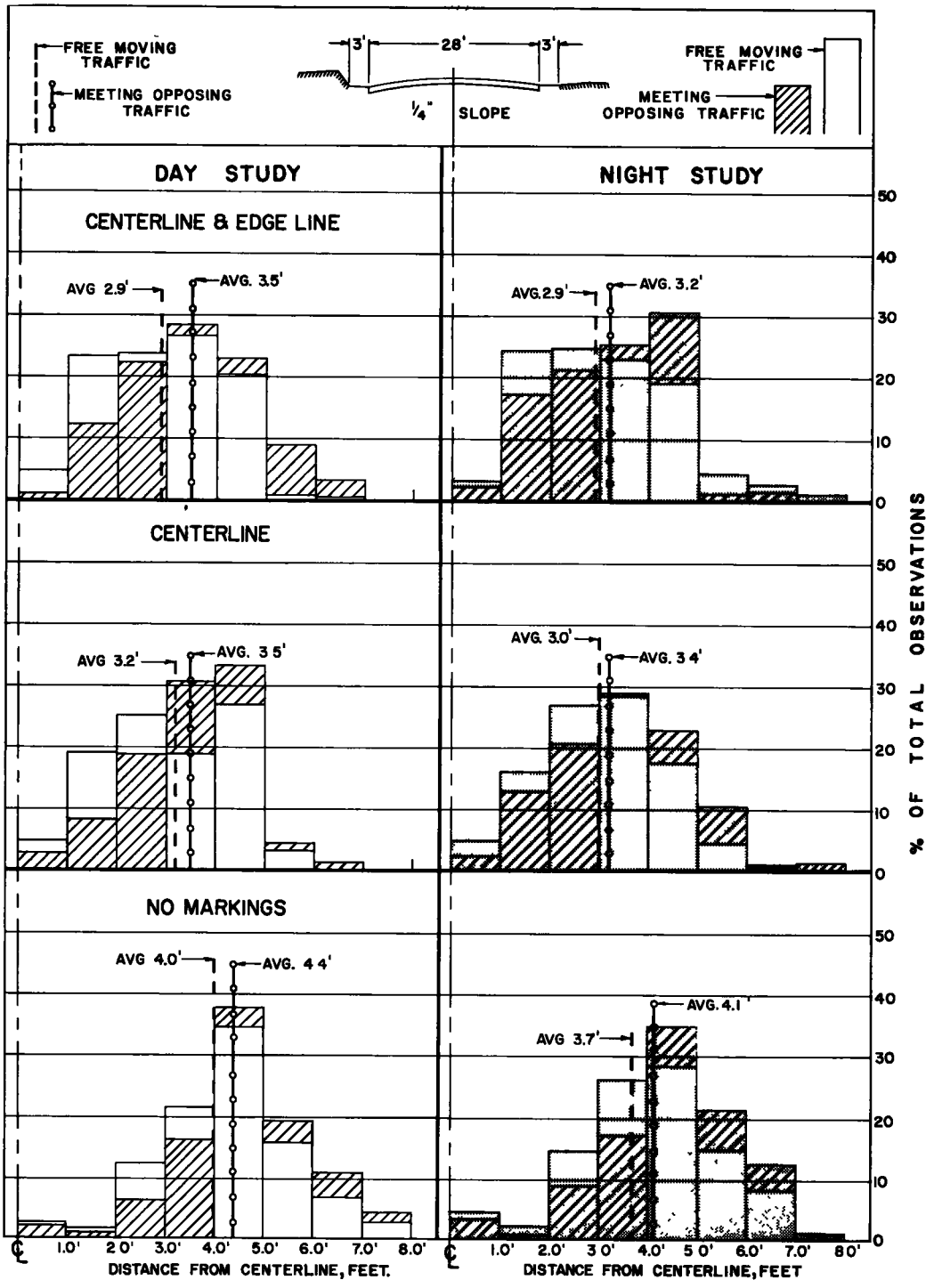

Figure 13. Farmington Station #2.

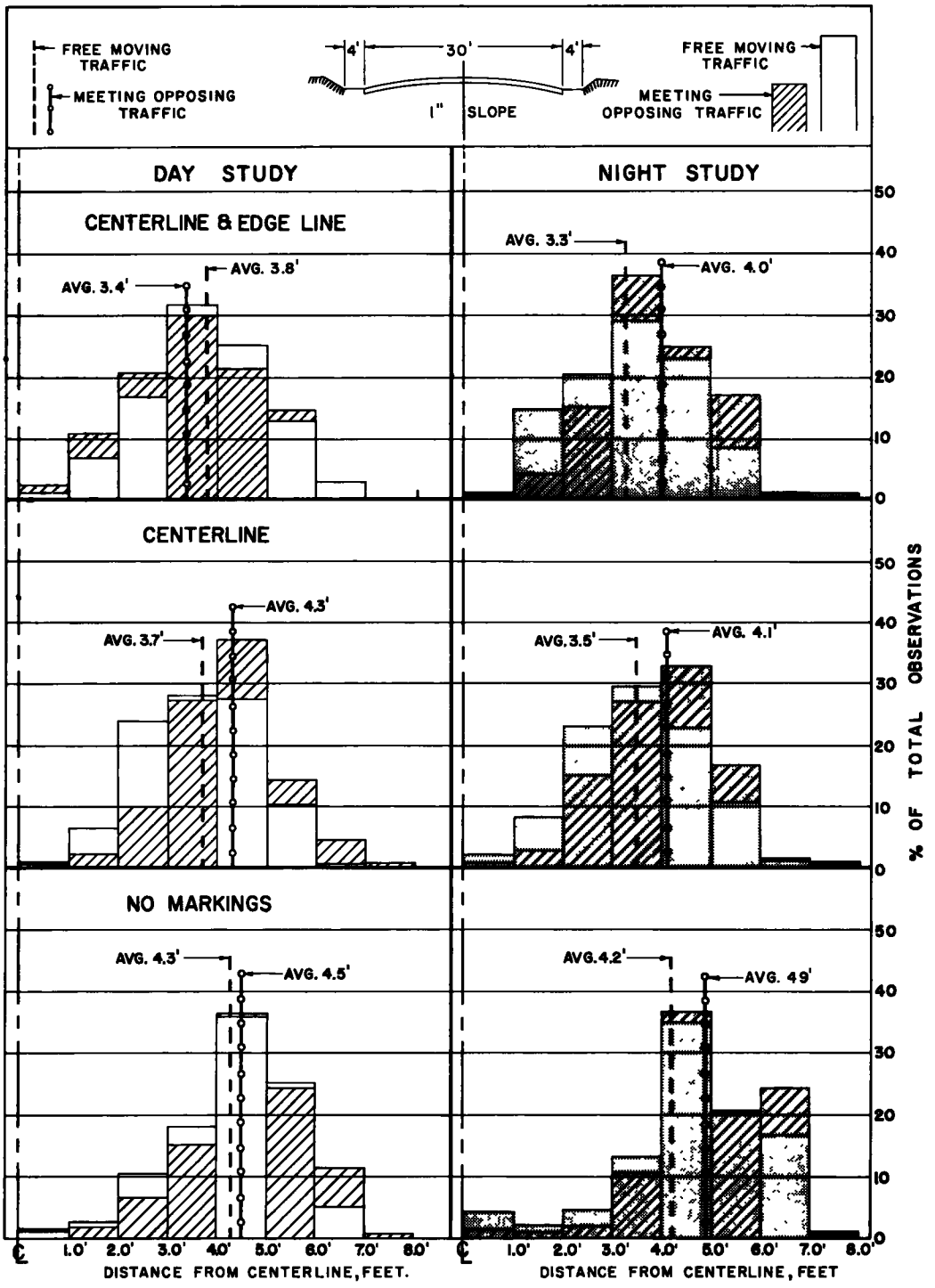

Figure 14. Farmington Station #3.

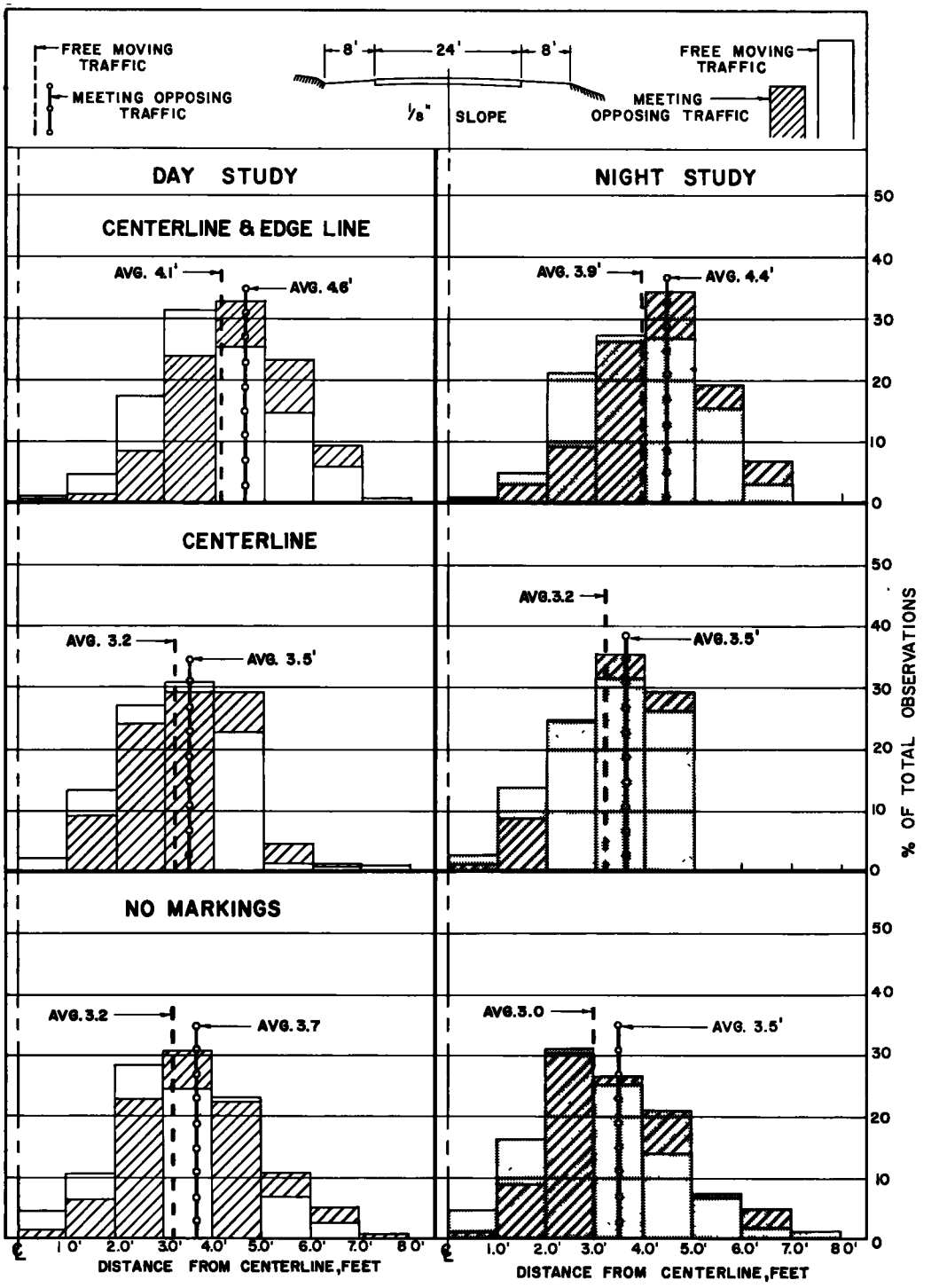

Figure 15. Farmington Station #4.

TABLE 4

MERRITT PARKWAY—SUMMARY OF ACCIDENTS TO RIGHT OF TRAVELWAY

Contributing Factors	1953		1955		1957	
	Lt.	Dk.	Lt.	Dk.	Lt.	Dk.
Driver inattentive	28	22	19	10	10	16
Surface condition	18	10	37	25	19	18
Driver asleep or incapacitated	10	13	2	12	13	17
Tire failure	4	7	5	2	9	3
Other mechanical failure	4	2	3	2	1	0
Passing maneuver	8	3	3	7	4	3
All others	3	2	7	0	3	4
Totals	75	59	76	58	59	61

ACCIDENT EXPERIENCE

At the four locations studied there appears to be no reliable data which might indicate possible accident reduction which might be related to the presence of a shoulder line.

Although no figures are presently available, it is generally accepted as factual within the Department that the pedestrian accidents, many of them fatal, at the first mentioned location where "shoulder lines" were placed were essentially eliminated.

The Merritt Parkway accident experience does reveal certain data which might indicate a reduction in accidents after the edge markings were placed (Table 4).

Table 4 is a summary of accidents in 1953, 1955, 1957 which involved vehicles leaving the roadway on the right-hand side. The inattentive classification is perhaps the only grouping that may indicate the influence of an edge line.

In 1953 when there were no edge markings there were 50 of this type accident (28 day—22 night). In 1955 one complete year with a white edge line shows 29 of this type accident (19 day—10 night). In 1957 one complete year with yellow edge lines there were 26 accidents of this type (10 day and 16 night).

CONCLUSIONS

1. On 2-lane and 4-lane divided highways the presence of a painted line along the outer edge of pavement affects the lateral position of vehicles. The most significant change in position occurs during darkness.
2. Some reduction in accidents involving vehicles leaving the roadway on the right is apparent on the 4-lane divided highway after an edge marking is placed.
3. The presence of an edge line along roadways where pedestrians

must use shoulders because of the absence of sidewalks offers additional security to both pedestrians and drivers.

4. It appears that an outer edge line provides pavement delineation and a point for a driver to focus his eyes when faced with oncoming headlights.

5. Edge markings appear to have some influence on operating speeds, a factor which might permit a deduction that the added delineation of the pavement edge increases driver confidence with a resulting safer operation.