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EFFECT OF RAISED PAVEMENT MARKERS ON TRAFFIC PERFORMANCE

Final Report

By

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16. Abstract

This project measured and documented the effect that snowplowable raised pavement markers (SRPM's) have on the behavior of traffic at certain geometric highway conditions. Two lane rural curves, highway exits with deceleration lanes and highway bifurcations were studied. Measures of performance selected to study the effects of the markers were: erratic maneuvers such as cutting through painted gores, weaving between exiting lanes, center and edge line encroachments; point of entrance into deceleration lanes; and mean speeds and speed variance at curves.

All types of erratic maneuvers studied were significantly reduced at various sites for traffic volumes up to 500 veh/hr/lane. At volumes between 900-1000 veh/hr/lane, the markers had no effect on traffic. Raised markers were not successful in causing motorists to enter deceleration lanes at exits earlier. As far as speeds, the markers seem to have caused a smoother speed profile through the two curves studied, resulting in less abrupt speed changes. The effect of SRPM's on speed variance was inconclusive.

The markers were effective in reducing erratic maneuvers at sites with and without overhead lighting. At one site, a high rate of erratic maneuvers during rain conditions was not only significantly reduced with the placement of markers, but the wet condition EM rate with the markers approached the quality of the dry condition rate.

A visual analysis of 15 different layouts of raised pavement markers at exits with deceleration lanes was performed and led to the placement of the devices on the gore at 20 ft., lane lines at 40 ft., and edge lines at 40 ft. spacings.

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SUMMARY AND RECOMMENDATIONS

This research project has gathered information which indicates that raised pavement markers are effective in altering driver performance under certain traffic and geometric conditions. Specifically, successful channelization of two-axle traffic and the reduction of erratic maneuvers and traffic conflicts at curves, exits, and bifurcations was achieved by the use of these markers for traffic up to 500 vph/lane. Data was also collected which shows that vehicles traversed the two curves studied with less extreme changes in speed. Sufficient data was gathered to study the effect these markers have on 3+ axle vehicles including large trucks. Generally, the traffic performance of these vehicles was unaffected by the presence of SRPM's. A visual analysis of 15 different layouts of the markers at exits with deceleration lanes was performed by a group of engineers and led to the placement of edge line markers at exits, a deviation from current practices.

The specific conclusions reached by the performance of this work are:

1) Raised pavement markers can significantly reduce the instances of erratic maneuvers through painted gores at exits and bifurcations for two-axle vehicles. The ability of the markers to affect traffic in this manner diminishes as volumes increase, probably due to the fact that the preceding vehicles block the view of the markers.
2) Raised pavement markers were not successful in causing drivers to utilize more of the deceleration lane at exits by entering the decel lane sooner. This was found for both two and 3+ axle vehicles.

3) The markers substantially reduced lane changes and encroachments for two-axle vehicles at a left side exit with two exit lanes.
4) Center line and edge line encroachments on two lane rural curves were significantly reduced for two-axle vehicles.
5) In general, the behavior of 3+ axle vehicles was not affected by the markers.
6) Speed profiles through the two curves were generally smoother in both rain and dry conditions. This conclusion is especially important since the reduction of extreme speed changes in a curve should lead to fewer conflicts between vehicles.
7) At the left side exit, lane changes and encroachments were significantly higher in rain when compared to dry conditions before the markers were installed. After installation, there was no significant difference between the percentage of erratic maneuvers during rain and dry conditions. This result supports the belief that raised pavement markers provide needed wet-night delineation and in this case, traffic performance under wet conditions approached the quality of traffic performance under dry conditions.
8) Raised pavement markers can reduce erratic maneuvers even in areas with street lighting. Gore maneuvers, lane weaves, center line encroachments, and extreme speed changes were all reduced at sites without and with overhead lighting.

9) Based on on-site observations by two engineers and the viewing of 16mm films of the various exit treatments by a group of engineers from Research, Traffic Engineering, Design, Maintenance, and Safety units, placement of raised pavement markers on the edge line of deceleration lanes at exits results in an earlier and more confident recognition of the exit.

Based on these conclusions, the Division of Research and Demonstration recommends the use of raised pavement markers where there is evidence that erratic maneuvers of the types studied in this project are occurring and where it is determined that increased delineation beyond paint lines is a requirement to alleviate the problem. This is not meant to exclude sites where other indicators of traffic problems exist, or to exclude other geometric configurations (tangent sections, narrow bridges, tapered exits, etc.) from consideration.

After a decision is made to delineate a road or section of road, we recommend the markers be placed as follows:

1) On two lane rural curves, the double yellow center line should be delineated with one row of markers between the two center lines. The spacing of the markers should be 80 feet on curves up to 3^{o}, 40 feet on curves between 3^{o} and 15^{o} and 20 feet on curves greater than 15^{o}. The markers should be visible to each direction of travel. Edge lines should be delineated with white markers at the same spacing as the center but should not be visible to the opposing direction of travel.

2) Highway exits should be marked with 20' spacing at the painted gore, 40' spacing on the lane line extending from the painted gore for half the length of the deceleration lane and on the edge line at 40' spacing from a point about 100 feet before the start of the deceleration lane up to the physical gore.
3) Bifurcations should be marked at 20' spacing from the tip to the physical gore.

It is also recommended that the markers be offset two to four inches from the painted line to avoid being painted over, unless a paint-skip device is used in the striping effort.

INTRODUCTION

This study was undertaken to determine whether snowplowable raised pavement markers (SRPM's) can reduce the variable behavior of traffic with regard to lane placement, choice of exit pathway and speed to the extent that traffic conflicts and erratic maneuvers are reduced. It is believed that the delineation provided by SRPM's would increase the driver's view of road and exit geometry and assist him in choosing a safe and efficient pathway.

OBJECTIVES

The study was designed to achieve the following objectives:

1. To measure the effect SRPM's have on center line and edge line encroachments on both lit and unlit curved sections of highway.
2. To measure the effect SRPM's have on speeds and speed variances on lit and unlit curves.
3. To measure the effect SRPM's have on the incidence of drivers

encroaching on painted gores, both at exits and at highway bifurcations.

4. To see whether SRPM's would cause motorists to enter the deceleration lanes at exits more consistently.
5. To visually determine what spacing and layout of SRPM's provides the best and earliest recognition of an exit and deceleration lane.

INSTALLATION PROCEDURES

Eight hundred raised pavement markers were installed at 11 sites in central and southern New Jersey. Amerace Corporation was contracted to provide the markers, concrete saw, epoxy dispensing machine and epoxy, and two machine operators. The New Jersey Department of Transportation provided safety operation, a water truck, and sufficient workers to assist in placing the markers.

STUDY DESIGN

Criteria for Site Selection

Potential sites were selected based on the following list of criteria:

1. Existence of higher than normal rates of run off the road accidents for a short section of highway.
2. Existence of a traffic performance problem such as encroachments, variability in exiting path, and weaving.
3. Subjective determination of the problem solving potential with the use of SRPM's.
4. Suitability of observation points for manual collection of data.

5. Suitability of collection of data by mechanical and photographic techniques.
6. Sufficient traffic volumes after dark to collect enough data for statsitical analysis.
7. Distance from the research office, a concern for collection of data under rain conditions.
8. Subjective determination of low potential vandalism of markers and/or mechanical counting devices.
9. Existence or lack of street lighting.

Pilot Studies at Potential Study Sites

A nighttime pilot study was performed at each site under consideration to determine what traffic characteristics should be studied at each location. The measures selected are listed in Table 1. The traffic maneuvers were defined as:

Center line encorachments - any wheel of the vehicle crosses over both yellow lines and encroaches on the opposing lane of travel.

Edge line encroachments - any wheel of the vehicle crosses over the white edge line and encroaches on the shoulder.

Gore encroachments - any wheel of the vehicle touches any part of the painted gore at an exit or highway bifurcation.

Longitudinal exit placement - deceleration lanes at exits were divided into two zones. The first sone started at the beginning of the deceleration lane and ended at a point halfway to the painted gore, where the lane line extending from the gore began. The second zone ran from this point up to the physical gore. If any wheel of an exiting vehicle touches Zone 1, it was considered a Zone 1 exit.

TABLE 1

SITE DESCRIPTIONS AND TRAFFIC PERFORMANCE MEASURES STUDIED

LOCATION	# LANES	LANE WIDTH	SHLDR. WIDTH	GORE LENGTH	DECEL LANE LENGTH	DEGREE OF CURVE	SPEED LIMIT	LIGHT-ING	MEASURES STUDIED
				CURVES					
Rt. 35	4 With 10' Painted Median	11'	None	--	--	6	35	Yes	1
Rt. 29	2	10'	4'	--	--	8	45	No	1,2,3
Rt. 206	2	10'	None	--	--	32	50	Yes	2
				BIFURCATIONS					
1 & 1A	Right Fork 2 Left Fork 2	12'	10'	400'	--	--	55	Yes	4
287	Right Fork 1 Left Fork 2	12'	12'	500'	--	--	55	No	4
				EXITS*					
440 & GSP	3 Thru 1 Right Exit	12'	10'	142'	410'	--	55	Yes	4,6
1 & 95	2 Thru 1 Right Exit	12'	10'	80'	650'	--	55	Yes	4,6
295 & 168	3 Thru 1 Right Exit	12'	None	170'	830'	--	55	Yes	4,6
295 & 38	3 Thru 1 Right Exit	12'	12'	140'	700'	--	55	Yes	4,6
29 & Market	3 Thru 2 Left Exit	13'	None	88'	730'	--	50	Yes	4,5
287 & 78	2 Thru 1 Right Exit	12'	12'	160'	580'	--	55	No	4,6
				CONTROL SITES					
29	2	10'	4'	--	--	5	45	No	1,2,3
440 & 9	3 Thru 1 Right Exit	12'	10'	134'	480'	--	55	Yes	4,6
295 & 561	3 Thru 1 Right Exit	12'	12'	140'	480'	--	55	Yes	4,6

MEASURES STUDIED

1 - Speeds
2 - Center Line Encroachments
3 - Edge Line Encroachments
4 - Gore Encroachments
5 - Lane Changes or Encroachments
6 - Longitudinal Exit Placement

*None of the exits in this study involved lane drops. All exits were parallel deceleration lane types.

Lane changes or encroachments - vehicles either completely changed lanes or encroached on the second exiting lane.

Vehicle speed - spot speeds were collected at selected locations.

Estimates of the frequency of each type of maneuver and traffic volumes were collected during the pilot studies and used to estimate the duration of data collection needed to gather enough samples for statistical analysis. The final locations for data collectors to position themselves at were decided during the pilot studies.

Data Collection Method

Most of the data was collected manually by observers at each site. Observation points which allowed the observers to be raised up, preferably over the roadway and hidden from view, were utilized. Such points were commonly on overpasses and railroad bridges. Where these did not exist, the observers were stationed on the side of the road on an embankment. Where this was not avaivable, pneumatic traffic counters were used to collect data. At exits, the observers counted total traffic, total exiting traffic, erratic maneuvers, and place of entry into the deceleration lane. This last piece of data was gathered by splitting the deceleration lane into two zones, with the division being at half the total length of the lane.

At curves, center line and edge line encroachments were gathered by visual observation at one site and by a combination of visual observation and an audio signal from a pneumatic traffic counter at another.

Speeds at curves were collected with a hand held radar unit.

At bifurcations, gore encroachments were counted using a visual and audio technique and traffic volumes were manually counted.

The audio technique mentioned above involved running hoses from pneumatic traffic counters to the center lines and edge lines of the curves studied and to the tip of the painted gore for the highway bifurcations. A car which encroached on the center or edge lines or the gore would trip the counter causing an audio signal which an observer stationed at the side of the road would record as an erratic maneuver (Figure 1).

SRPM Placement and Spacing at Exits

In order to determine where and at what spacing SRPM's should be put at exits and deceleration lanes, the following study was conducted.

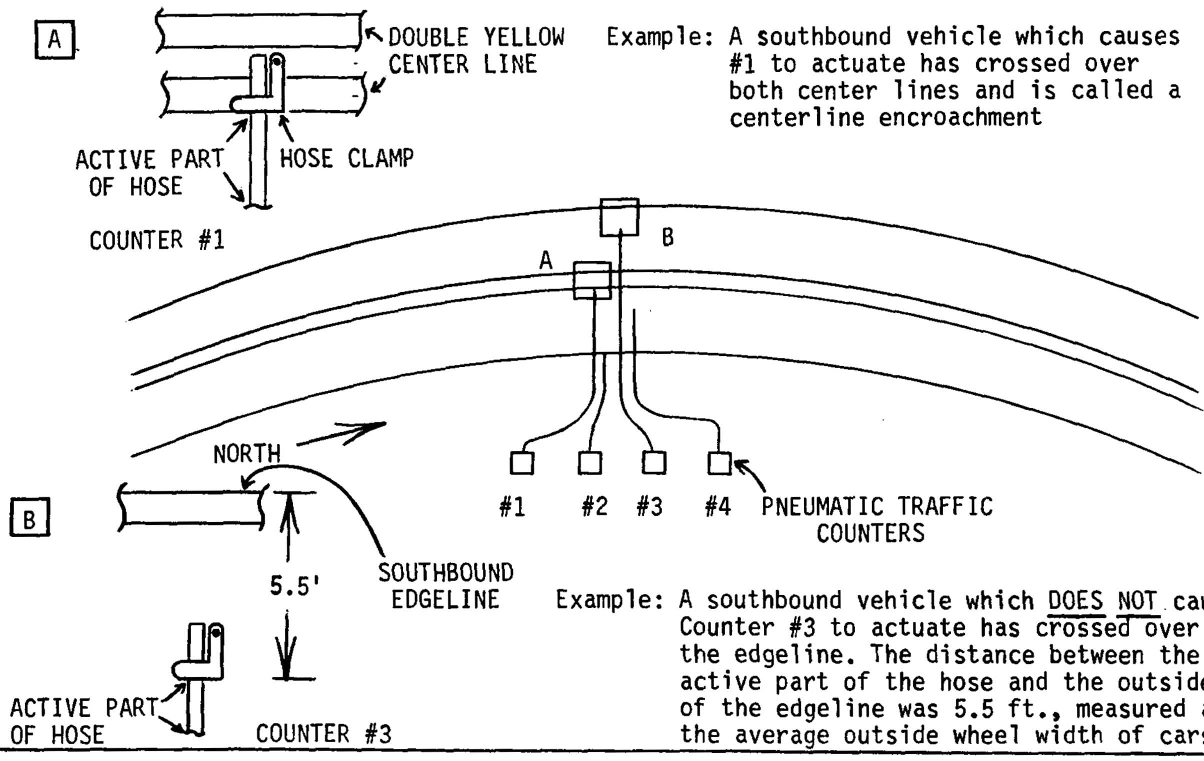
Fifteen different layouts of SRPM's (Figures 5-7 in Appendix B) were installed (without castings) on a New Jersey highway. Two engineers drove past the exits, made observations of the visibility of the devices and recognizability of the layout as an exit. Thirty-five millimeter color slides and 16mm color motion pictures were taken of each layout. These pictures were shown to a group of engineers from Traffic Engineering, Traffic Operations and Safety, Surface Design, Maintenance, and Research. Consensus was reached to use Layout #6 in the research project. This layout puts markers on the painted gore at 20' spacing, on the lane line extending from the gore at 40' spacing for half the length of the deceleration lane, and on the edge line at 40' spacing, starting 100 feet before the deceleration lane starts and ending at the physical gore.

Statistical Analysis

From the pilot studies, estimates of the time of data collection needed to collect sufficient samples for statistical analysis were

FIGURE 1

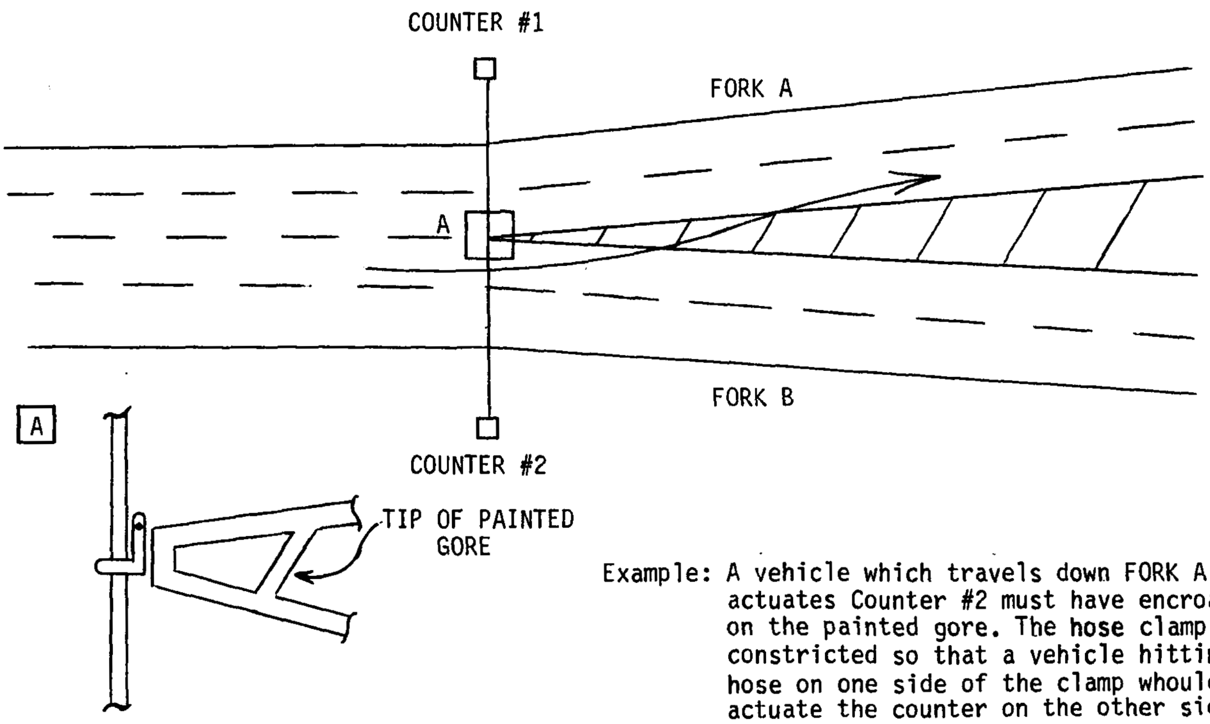
DATA COLLECTION TECHNIQUE ON TWO LANE, RURAL CURVES



Example: A southbound vehicle which causes #1 to actuate has crossed over both center lines and is called a centerline encroachment

Example: A southbound vehicle which DOES NOT cause Counter #3 to actuate has crossed over the edgeline. The distance between the active part of the hose and the outside of the edgeline was 5.5 ft., measured as the average outside wheel width of cars.

DATA COLLECTION TECHNIQUE ON HIGHWAY BIFURCATIONS



Example: A vehicle which travels down FORK A but actuates Counter #2 must have encroached on the painted gore. The hose clamp was constricted so that a vehicle hitting the hose on one side of the clamp whould not actuate the counter on the other side.

generated. The number of erratic maneuvers aimed at for each site was 30, and the number of free flowing spot speed samples was 100. However, at some sites these numbers were not reached, but the sampling requirements of the statistical tests used still allowed the analysis to be performed. The specific tests used for each type of maneuver are described as follows:

1. Test of Proportions (1):

$$Z = \frac{p_1 - p_2}{\sqrt{(pq)\left[(1/N_1) + (1/N_2)\right]}}$$

$$p_1 = \frac{n_1}{N_2} \qquad p_2 = \frac{n_2}{N_2} \qquad p = \frac{n_1 + n_2}{N_1 + N_2} \qquad q = 1 - p$$

n_1 = number of "before" erratic maneuvers

n_2 = number of "after" erratic maneuvers

N_1 = traffic volume "before"

N_2 = volume "after"

This test was used to analyze the effect SRPM's had on gore encroachments, longitudinal exit placement, lane weaves and center line and edge line encroachments. The test was applied, "If the smaller value of p or q multiplied by the smaller value of N exceeds five." (2) From the values of Z calculated by this test, the level of significance for the change in erratic maneuver rates was taken from a Normal Curve. For purposes of the discussion, conclusions and recommendations, a level of 95% or greater was considered significantly different for all statistical tests used.

2. t - test (3):

$$t = \frac{X_1 - X_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

X_1 = mean of "before sample

X_2 = mean of "after" sample

S_1 = standard deviation of "before" sample

S_2 = standard deviation of "after" sample

N_1 = "before" samples

N_2 = "after" samples

This test was used to analyze the differences in mean speeds attributable to the installation of the markers.

3. F - test (4):

$$F = \frac{\sigma_1^2}{\sigma_2^2} \qquad \left.\begin{array}{l} F_1 = N_1 - 1 \\ F_2 = N_2 - 1 \end{array}\right\} \text{degrees of freedom}$$

σ_1^2 = variance of "before" or "after" sample

σ_2^2 = variance of "after" or "before" sample

N_1 = sample size used to compute σ_1

N_2 = sample size used to compute σ_2

The larger variance is designated σ_1^2 and used as the numerator whether it is the "before" or "after" sample.

This test was used to analyze differences in the variance between the "before" and "after" speed samples.

RESULTS - EFFECT OF SRPM'S ON TWO AXLE VEHICLES

Effect of SRPM's on Erratic Maneuvers Through the Painted Gore At Exits

Six sites out of nine experienced statistically significant reductions in the percentage of cars which cut through the painted gore, while the two control sites did not significantly change (Table 2). Two sites (Route 29 and Route 168 during the earlier data collection period) did not change significantly and these sites, when studied under rain conditions, experienced an increase in the percentage of erratic maneuvers.

Route 29 was the only left side exit studied and the incidence of gore maneuvers was very small in the before studies, so the lack of a significant change is not surprising. This site was studied because it had two exiting lanes between which a considerable amount of weaving took place. The effect of the markers on this weaving is discussed later.

The fact that the Route 168 site had an insignificant change during dry and wet conditions is somewhat perplexing. However, when the same site was studied later in the evening, a significant reduction in erratic maneuvers did occur. There was a large difference in the traffic volume for the two different times of data collection -- 950/hr./lane in the earlier period and 400/hr./lane in the latter. If the traffic was spaced evenly over the three lanes for each condition, the average spacing between vehicles would be about 300 feet for the earlier time and about 750 feet for the later period. It is conceivable that the closer average spacing in the first condition diminished the ability of the motorist to view enough of the exit markers in order to recognize the pattern. This

TABLE 2

Effect of SRPM's on Gore Encroachments

by 2 Axle Vehicles at Exits

Site	Before			After			Change	Level of Signif.	VPH/ Lane
	Total Vehicles	Gore Enc.	%	Total Vehicles	Gore Enc.	%			
Time of Data Collection: 5:30 pm to 7:00 pm									
29	2383	18	0.76	1880	13	0.69	-.07	<50%	250
29(Rain)	310	1	0.32	725	8	1.10	+.78	*	250
1 & 95	1691	59	3.49	1883	13	0.69	-2.80	>99%	450
295 & 38	3935	52	1.32	3586	12	0.33	-.99	>99%	450
440 & GSP	4039	42	1.04	4082	17	0.42	-.62	>99%	500
295 & 168	8077	27	0.33	7445	21	0.28	-.05	<50%	950
295 & 168(Rain)	2738	15	0.55	2397	14	0.58	+.03	<50%	950
Controls									
440 & 9	5034	46	0.91	5251	39	0.74	-.17	65%	650
295 & 561	5271	27	0.51	7508	51	0.68	+.17	79%	900
Time of Data Collection: 8:00pm to 10:00 pm									
440 & GSP	2781	23	0.83	3957	15	0.38	-.45	98%	250
295 & 168	4721	38	0.80	7872	19	0.24	-.56	>99%	400
287 & 78 (no lighting)	2785	14	0.50	5665	13	0.23	-.27	>99%	200

* insufficient data to apply statistical tests

TABLE 3

Percentage of 2 Axle Exiting Vehicles Entering the First Half (Zone 1) of the Deceleration Lane (Fig. 2)

Time of Data Collection: 5:30 pm-7:00 pm 1 hr

Sites	Before-Treatment A: Exiting Vehicles	Exits in Zone 1	%	After-Treatment C: Exiting Vehicles	Exits in Zone 1	%	Change	Level of Signif.
295 & 168*	1876	1354	72.2	1823	1160	63.6	-8.6	>99%
295 & 38	1026	953	92.9	993	897	90.3	-2.6	96%
1 & 95	96	83	86.5	108	98	90.7	+4.2	65%
440 & GSP	1735	206	11.9	1749	344	19.7	+7.8	>99%
Controls								
440 & 9	955	714	74.8	1137	723	63.6	-11.2	>99%
295 & 561	1154	1086	94.1	1594	1461	91.7	-2.4	98%

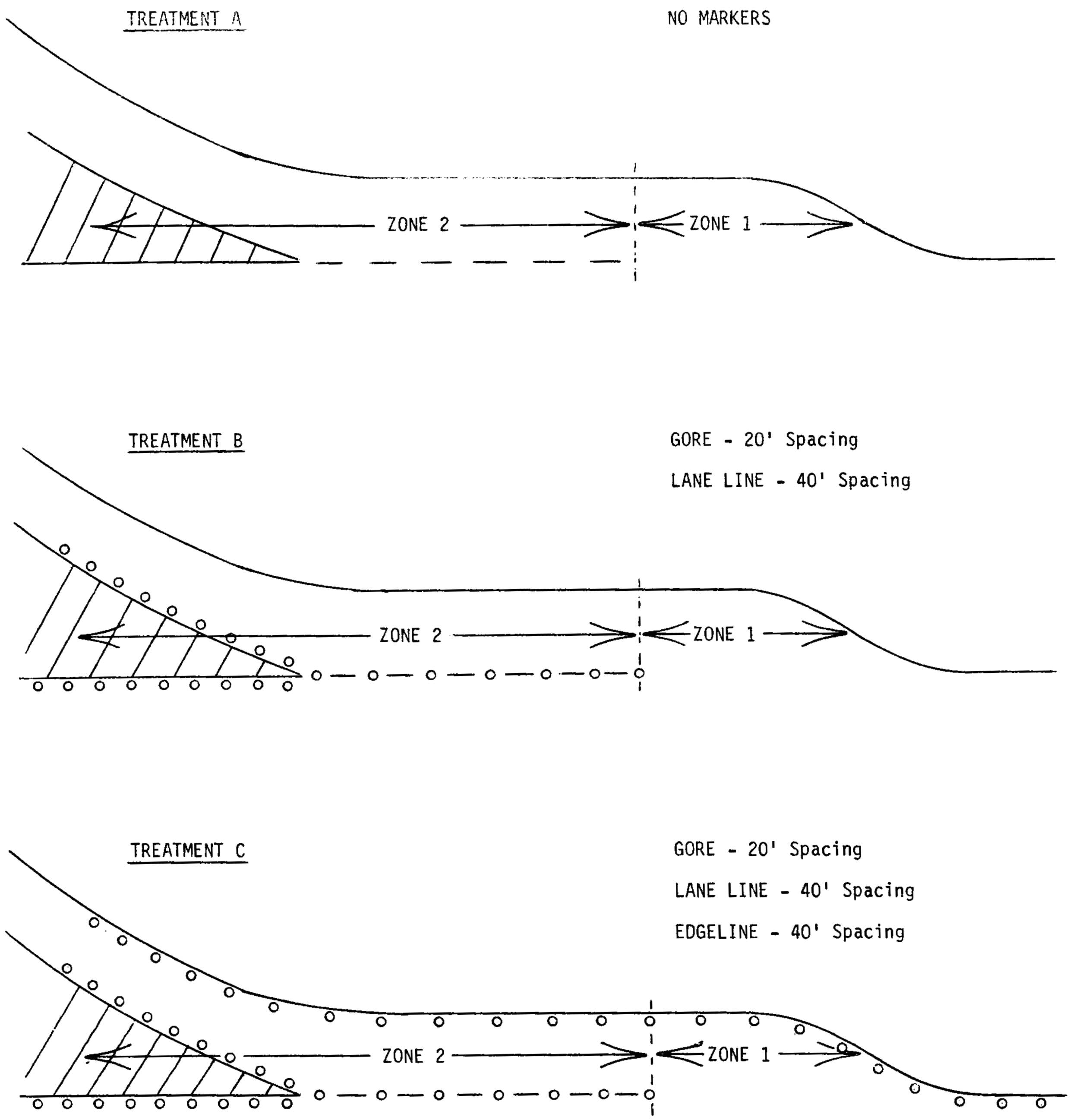
* For 295 & 168, data compiled in axles, not vehicles.

Time of Data Collection: 8 pm - 10 pm 2 hrs

Site	Before-Treatment A: Exits	Zone 1	%	Middle-Treatment B: Exits	Zone 1	%	After Treatment C: Exits	Zone 1	%	Change A→B	Level Sig.	Change B→C	Lev. Sig.
440 & GSP	989	79	8.0	985	234	23.8	378	68	18.0	+15.8	>99%	-5.8	97%
295 & 168*	1342	856	63.8	1142	886	77.6	1218	730	59.9	+13.8	>99%	-17.7	>99%
287 & 78 (no lighting)	216	161	74.5	236	212	89.8	232	197	84.9	+15.3	>99%	-4.9	88%

FIGURE 2

MARKER LAYOUTS FOR LONGITUDINAL EXIT PLACEMENT STUDIES



may account for the lack of response to the markers under the higher volume condition.

Effect of SRPM's on Choice of Exiting Path

Data was collected at four study sites and two control sites to see whether the SRPM's would cause more drivers to exit earlier in the deceleration lane (Figure 2, Treatments A & B). The percentage of exiting vehicles which exited in Zone 1 was collected before and after the installation of the markers.

Although the percentage of exiting in Zone 1 changed significantly for all study sites except Route 1 & 95 (Table 3), the fact that the control sites experiences significant changes of a similar magnitude prohibits assigning responsibility for the changes to the application of SRPM's.

The results of the study on the addition of edge lines and their effect on choice of exiting path are also listed in Table 3. One "trend" does not exist for this data. When the gore and lane line was marked (Treatment B), all three sites had an increase in the percentage of Zone 1 exits. When edge line markers were added, all three sites had a decrease in the percentage of Zone 1 exits when compared to Treatment B.

Effect of SRPM's on Lane Changes and Encroachments Between Two Exiting Lanes

The incidence of lane changes and encroachments between two exiting lanes on a left exit was significantly reduced with the application of SRPM's in both wet and dry conditions. In the rain when these maneuvers were more prevalent than in the dry condition, the reduction was greater and the percentage of erratic vehicles in the rain (44%) approached the percentage of erratic vehicles in the dry condition (38%) when SRPM's were present.

SITE	BEFORE TOTAL EXITS	BEFORE EM's	BEFORE %	AFTER TOTAL EXITS	AFTER EM's	AFTER %	% CHANGE IN EM RATE	LEVEL OF SIGNIFICANCE
Rt. 29 - Dry	939	528	56.2	941	365	38.8	-31	>99%
Rt. 29 - Rain	139	100	71.9	308	134	43.5	-39	>99%

Effect of SRPM's on Gore Encroachments at Highway Bifurcations

The percentage of vehicles cutting across the painted gore at bifurcations was drastically reduced both for a lit and unlit site. No control site was studied for comparison, however, the magnitude of the change alone is a telling statistic.

SITE	LENGTH OF GORE	TOTAL VEHICLES	GORE ENC.	%	TOTAL VEHICLES	GORE ENC.	%	% CHANGE IN EM RATE	LEVEL OF SIGNIFICANCE
Rt. 1 & 1A	400 ft.	3674	135	3.67	3446	60	1.74	-53	>99%
Rt. 287 (No lighting)	500 ft.	3983	96	2.41	3544	22	0.62	-74	>99%

Effect of SRPM's on Encroachments at Two Lane Rural Curves

Center line and edge line encroachments were reduced at the study sites by significant amounts while a control site change by non-significant amounts (Table 4). Unaccountably, the change at Route 206 which has a good deal of street lighting was larger than at Route 29 which has no lighting.

The importance of minimizing center line encroachments is easily apparent. The reduction of edge line encroachments might not seem as important since conflict with other vehicles is not likely to occur. However, on a road line Route 29, which is dark with trees and

TABLE 4

Effect of SRPM's on Centerline and Edgeline Encroachments by 2 Axle Vehicles on Two-Lane, Rural Curves

Site	Before Total Veh.	Before Enc.	Before %	After Total Veh.	After Enc.	After %	Change	Level of Signif.
Centerline Encroachments								
Rt. 206	1044	162	15.5	972	34	3.5	-12.0	>99%
Rt. 29 (no lighting)	675	78	11.6	406	32	7.9	- 3.7	95%
Control Site								
Rt. 29 (no lighting)	707	14	2.0	733	17	2.3	+0.3	<50%
Edgeline Encroachments								
Rt. 29 (no lighting)	1072	107	10.0	609	26	4.3	-5.7	> 99%
Control Site								
Rt. 29 (no lighting)	450	36	8.0	457	32	7.0	-1.0	<50%

telephone poles within a couple of feet of the edgeline, reduction of this type of erratic maneuver may be considered beneficial.

Results - Effect of SRPM's on 3+ Axle Vehicles

As previously stated, 3+ axle vehicles were differentiated from 2 axle vehicles during data collection for the following reasons:

1. The greater vertical separation between the driver and the headlights may affect the visibility of the retroreflective devices.
2. Three plus axle vehicles have reduced maneuverability, which may inhibit their ability to react to the SRPM's.

Sufficient data was collected at nine sites to analyze the change from the before to the after condition for statistical significance. As previously outlined, the test for difference in Proportions and the rule of thumb for determining whether sufficient data exists for applying the test were used in this analysis.

Table 5 shows the results of this analysis. Only one site, Route 295 & 38, experienced a change with a level of significance greater than 95%. Therefore, the general conclusion that SRPM's do not affect the traffic performance of 3+ axle vehicles with respect to the types of maneuvers studied can be reached.

TABLE 5

Effect of SRPM'S on Erratic Maneuvers
by 3+ Axle Vehicles

EXITS

Site	BEFORE Veh.	BEFORE Gore Enc.	BEFORE %	AFTER Veh.	AFTER Gore Enc.	AFTER %	Change	Level of Signif.
Peak Period								
295 & 168	457	15	3.3	378	8	2.1	-1.2	68%
295 & 168(Rain)	125	6	4.8	137	8	5.8	+1.0	< 50%
295 & 38	444	66	14.9	438	13	3.0	-11.9	99%
Control								
295 & 561	338	14	4.1	547	15	2.7	-1.4	74%
Off-Peak								
295 & 168	527	6	1.1	505	10	2.0	+0.9	71%

2 Lane Rural Curves

Site	BEFORE Veh.	BEFORE Total Enc.*	BEFORE %	AFTER Veh.	AFTER Total Enc.	AFTER %	Change	Level of Signif.
206	32	8	25.0	43	9	20.9	-4.1	< 50%
29	64	11	17.2	36	7	19.4	+2.2	< 50%
Control								
29	50	12	24.0	47	6	12.8	-11.2	84%

* Centerline + Edgeline Encroachments

Bifurcations

Site	BEFORE Veh.	BEFORE Gore Enc.	BEFORE %	AFTER Veh.	AFTER Gore Enc.	AFTER %	Change	Level of Signif.
287	444	12	2.7	377	4	1.1	-1.6	91%

Results - Effect of SRPM's on Vehicle Speeds at Curves

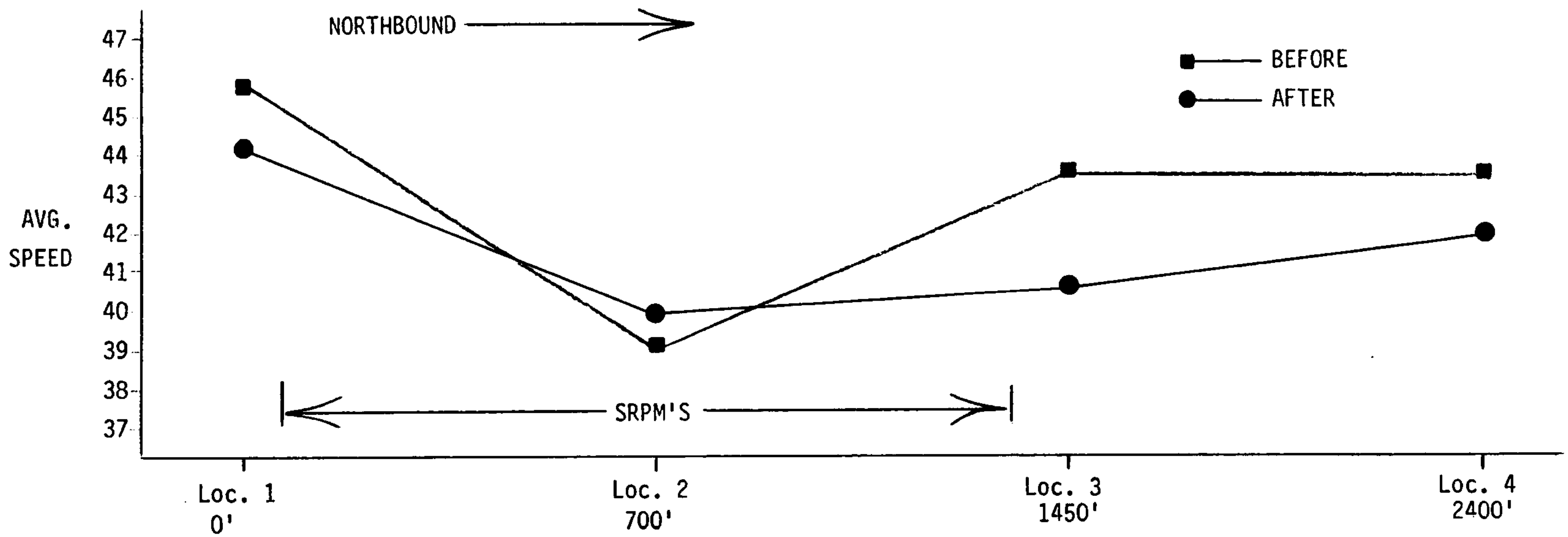
Route 29, Hopewell

Speeds were collected at four locations in both the north and southbound directions. Location 1 was at the beginning of the south end of the installation, Location was at the apex of the curve, Location 3 was at the north end of the installation, and Location 4 was about 1,000 feet north of the installation around a curve. At Location 4 (a control site), no markers were visible to motorists. At Locations 1, 2, and 3, the markers were visible. Lack of a suitable place for parking the car out of the motorist's view prevented the collection of speeds at a control site south of the installation.

The SRPM's appear to have caused a smoother speed profile through the site in both the northbound and southbound directions (Figure 3 and Table 6). This is evidenced by the smaller changes in speed which occurred between the data collection points after the markers were installed. The lower speeds measured as cars entered the site in the after condition Location 1, NB and Location 3, SB) indicate that the markers gave the motorists a cue that the curve was nearing and prompted them to begin deceleration earlier. The fact that speeds increased at the apex of the curve (Location 2) after the markers were placed, may be due to the increased confidence imparted to the motorists by the improved view of the curve geometry. The combined effect of these pehnomena was the smoothing of the speed profile.
At Location 4, in the southbound direction, no difference occurred between the speeds collected in the before and after conditions at the 95% level of confidence. As previously stated, this was the only true control site where motorists could neither see nor had passed

FIGURE 3

EFFECT OF SRPM'S ON SPEEDS AT RT. 29



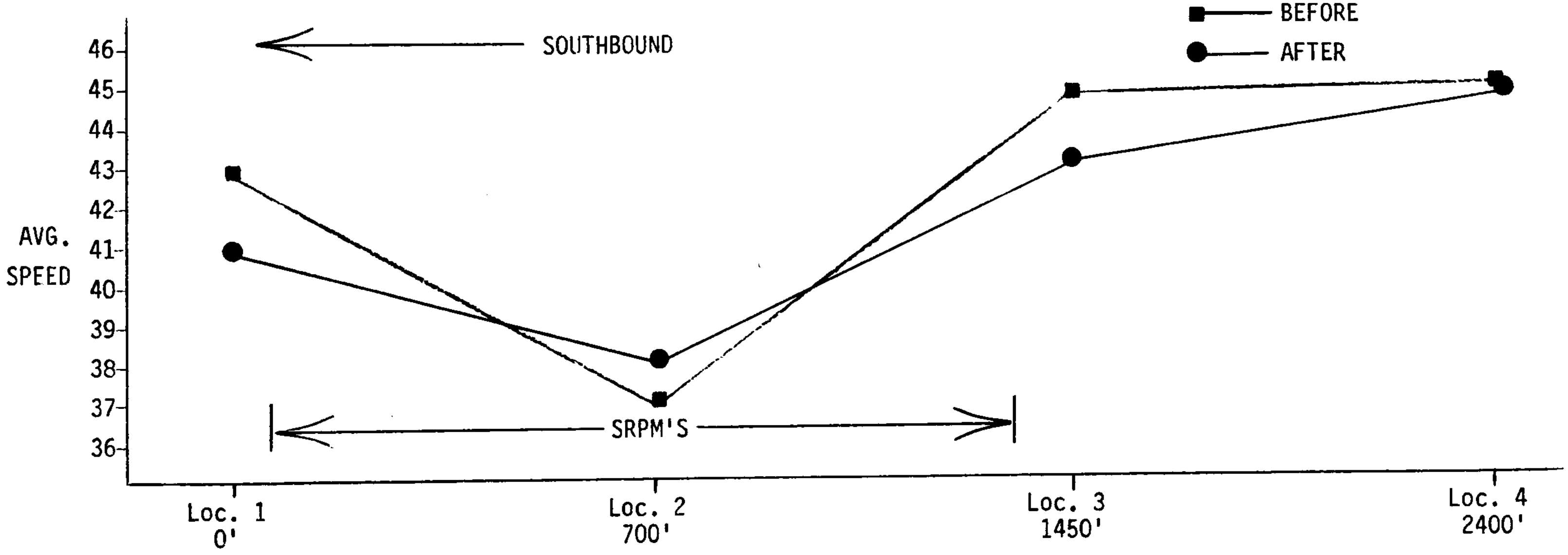


TABLE 6

Analysis of Mean Speeds and Speed Variance
at Rt. 29

Direction and Location	Measure	Before	After	Change	Level of Significance
Location 1 NB	$\bar{x}$	45.8	44.1	-1.7	>99%
	σ	4.2	4.7	-	
	σ^2	17.6	22.1	+4.5	>95%
	n	187	215	-	
Location 1 SB	$\bar{x}$	42.8	40.9	-1.9	>99%
	σ	5.2	4.6	-	
	σ^2	27.0	21.2	-5.8	<95%
	n	121	147	-	
Location 2 NB	x	39.0	39.9	+0.9	97%
	σ	3.9	4.1	-	
	σ^2	15.2	16.8	+1.6	<95%
	n	194	177	-	
Location 2 SB	$\bar{x}$	36.8	38.0	+1.2	98%
	σ	4.5	4.6	-	
	σ^2	20.3	21.2	+0.9	<95%
	n	170	139	-	
Location 3 NB	$\bar{x}$	43.4	40.6	-2.8	>99%
	σ	4.4	4.5	-	
	σ^2	19.4	20.3	+0.9	<95%
	n	176	249	-	
Location 3 SB	$\bar{x}$	44.7	42.9	-1.8	>99%
	σ	4.7	5.0	-	
	σ^2	22.1	25.0	+2.9	<95%
	n	162	210	-	
Location 4 NB	$\bar{x}$	43.4	42.0	-1.4	>99%
	J	4.1	4.5	-	
	J^2	16.8	20.3	+3.5	<95%
	n	171	192	-	
Location 4 SB	$\bar{x}$	44.8	44.8	0	--
	J	4.2	4.1	-	
	J^2	17.6	16.8	-0.8	<95%
	n	137	185	-	

through the installation. The difference in speeds at Location 4 for cars traveling north could be a residual effect of the motorists having just traversed the site. Since the SRPM's caused a smoothing of the speed profile, the motorists seemed to be continuing this effect by gradually increasing their speed.

Speed variance at the four locations did not change by statistically significant amounts when the SRPM's were added (Figure 4 and Table 6).

Route 35

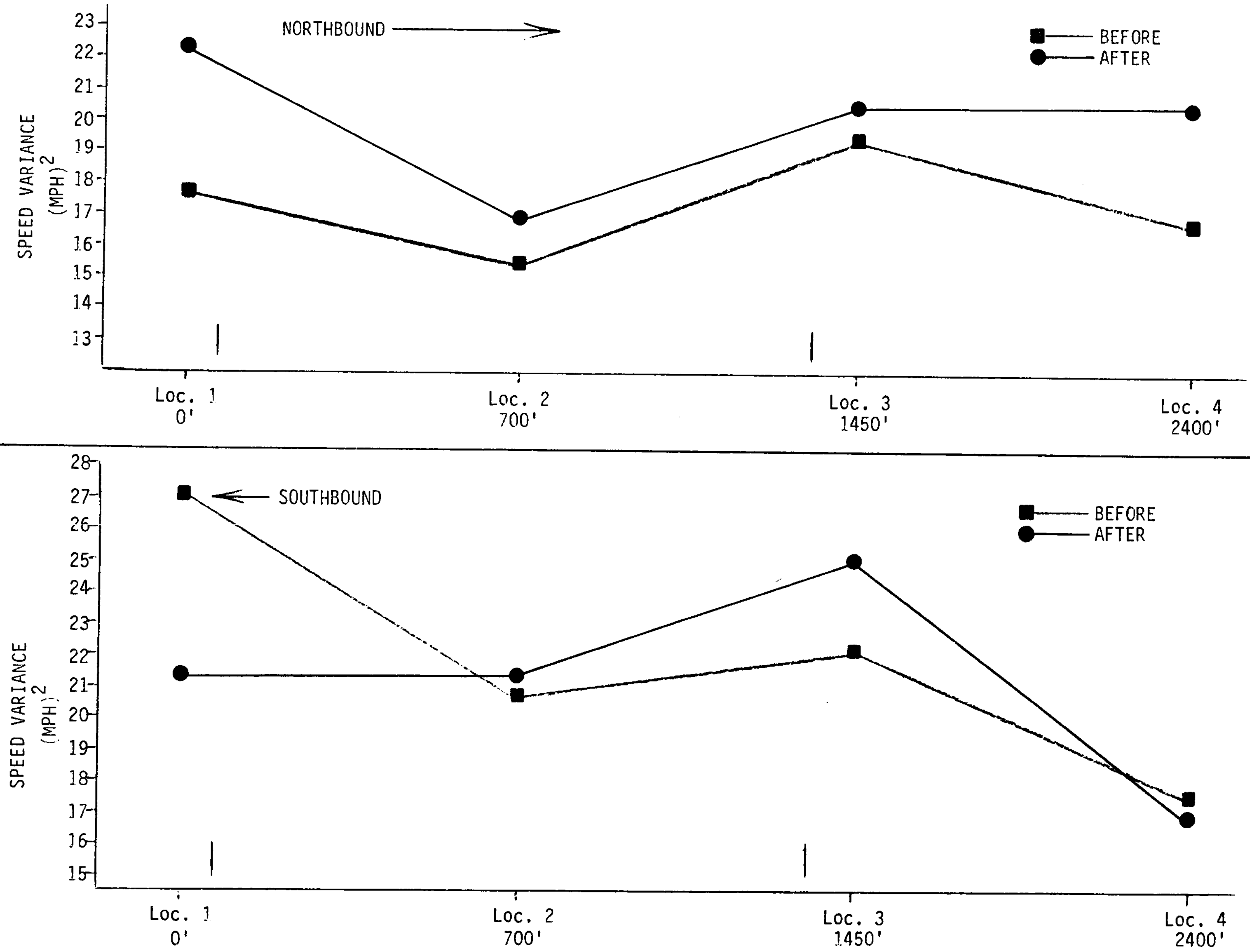
Speeds were collected at three locations, northbound and southbound, during rain and dry conditions. At Location 1, northbound vehicles could neither see nor had passed through the installation while southbound vehicles had just gone through the site. Locations 2 and 3 were in the site roughly at each end of the installation. Lack of suitable Parking places prevented speeds from being measured north of the site or at the apex of the curve.

There appears to be trend toward a smoother speed profile when the markers were present with the exception of the cars traveling north in the dry condition (Figure 5). As with the previous analysis on Route 29, this is probably due to the cue the driver receives concerning road geometry which causes an earlier deceleration. In general, speeds were reduced after the SRPM's were installed with Location 2 for southbound cars showing an increase in speed under wet conditions. The control site, Location 1 for northbound vehicles, showed insignificant changes in both speed and speed variance when comparing the before and after conditions (Tables 7 and 8).

The effects of the addition of the markers on speed variance

FIGURE 4

EFFECT OF SRPM's ON SPEED VARIANCE AT RT. 29



EFFECT OF SRPM'S ON VEHICLE SPEEDS AT RT. 35, BELMAR

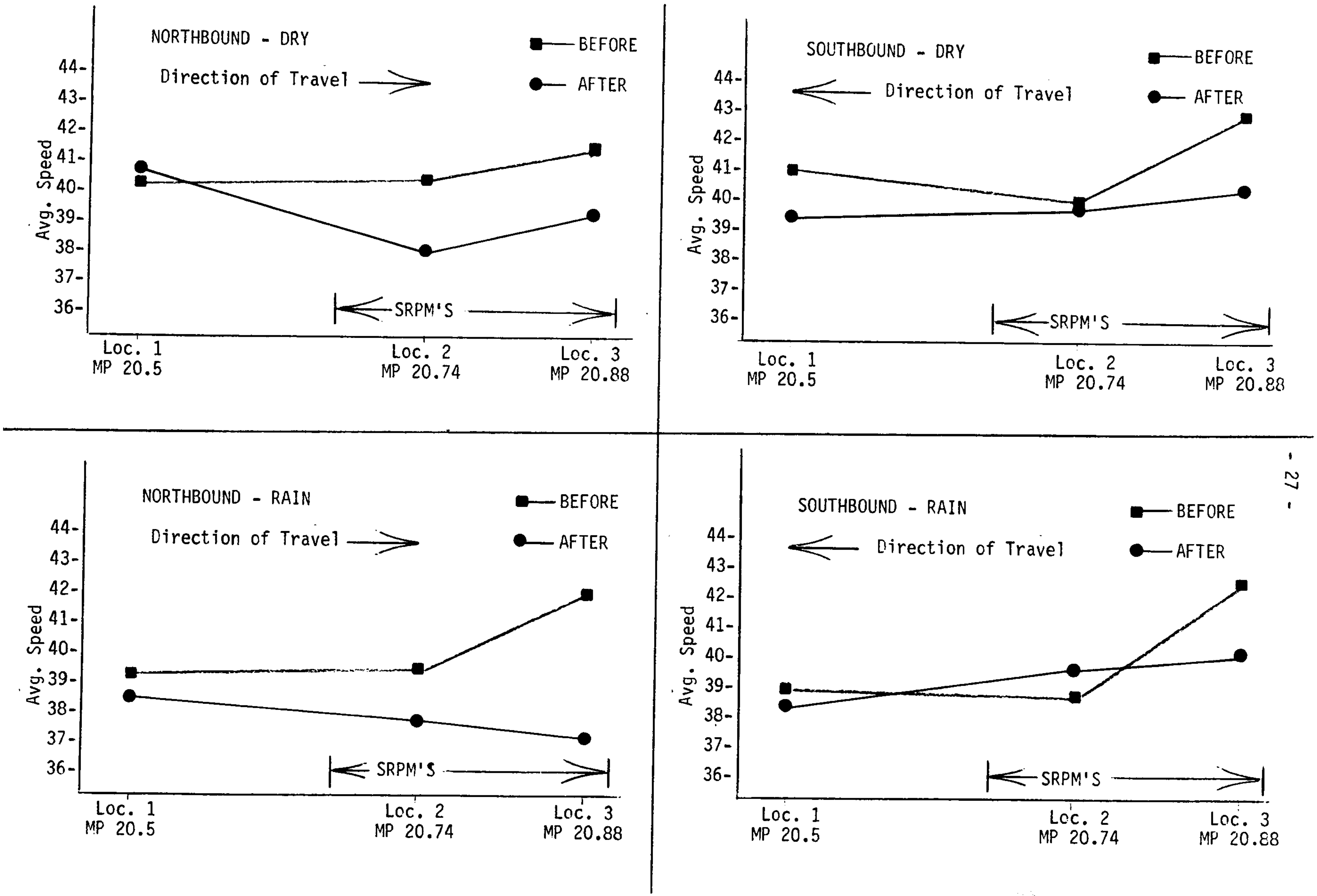


TABLE 7

Analysis of Mean Speeds and Speed Variance

at Rt.35, Dry Conditions

Direction and Location	Measure	Before	After	Change	Level of Significance
Location 1	$\bar{x}$	40.3	40.6	+0.3	<50%
NB	σ	4.1	4.7	–	
	σ^2	16.8	22.1	+4.3	<95%
	n	66	123	–	
Location 1	$\bar{x}$	41.1	39.5	-1.6	>99%
SB	σ	4.1	4.5	–	
	σ^2	16.8	20.3	+3.5	<95%
	n	94	147	–	
Location 2	$\bar{x}$	40.7	38.1	-2.6	>99%
NB	σ	4.7	3.7	–	
	σ^2	22.1	13.7	-8.4	>95%
	n	97	180	–	
Location 2	$\bar{x}$	40.1	39.9	-0.2	<50%
SB	σ	4.3	4.0	–	
	σ^2	18.5	16.0	-2.5	<95%
	n	89	179	–	
Location 3	$\bar{x}$	41.5	39.4	-2.1	>99%
NB	σ	5.3	4.9	–	
	σ^2	28.1	24.0	-4.1	<95%
	n	109	165	–	
Location 3	$\bar{x}$	43.1	40.5	-2.6	>99%
SB	σ	4.3	4.1	–	
	σ^2	18.5	16.8	-1.7	<95%
	n	98	148	–	

TABLE 8

Analysis of Mean Speeds and Speed Variance

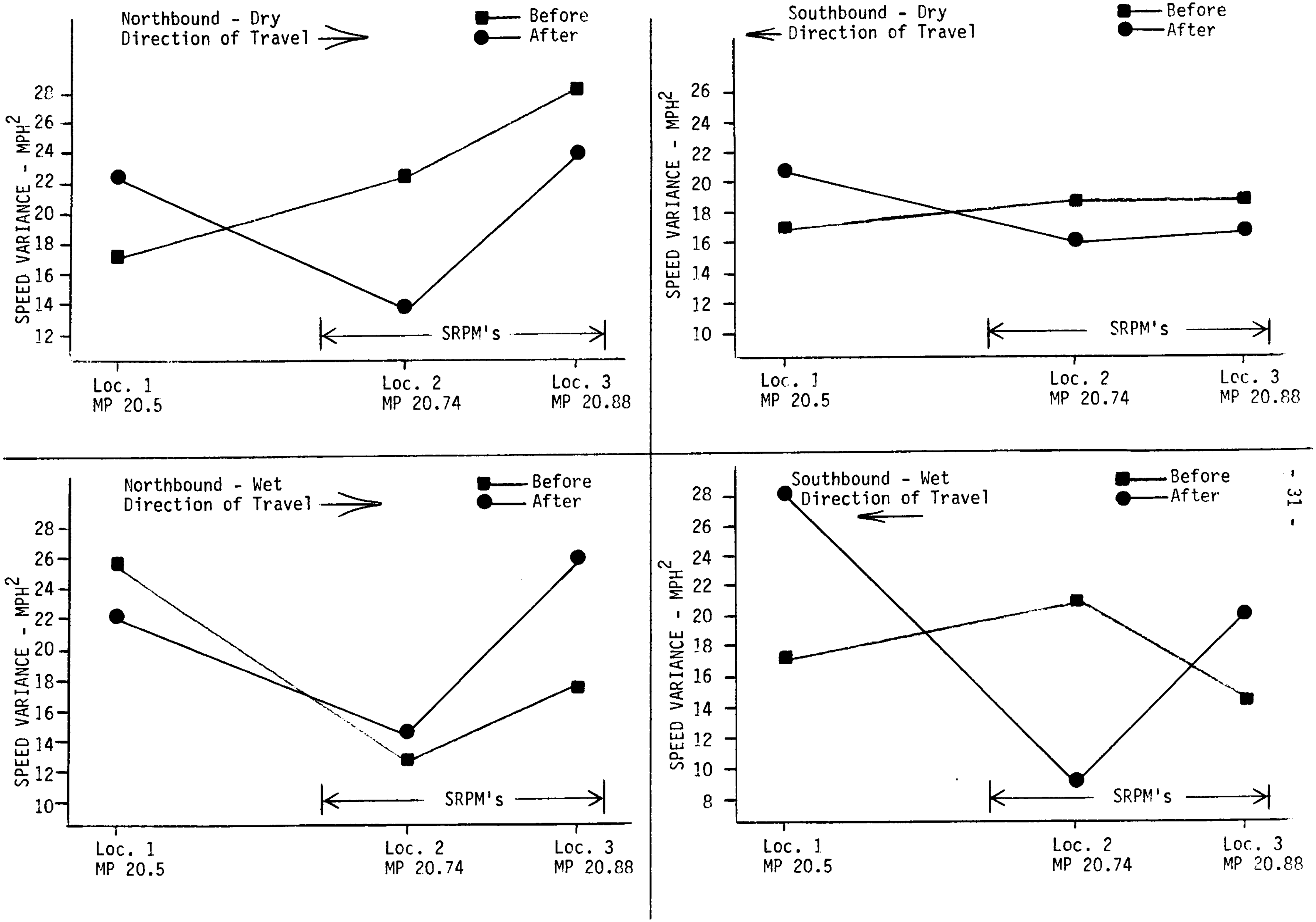
at Rt. 35, Rain Condition

Direction and Location	Measure	Before	After	Change	Level of Significance
Location 1 NB	$\bar{x}$	39.2	38.6	-0.6	<50%
	σ	5.1	4.7	-	
	σ^2	26.0	22.1	-3.9	<95%
	n	60	33	-	
Location 1 SB	$\bar{x}$	38.9	38.6	-0.3	<50%
	σ	4.2	5.3	-	
	σ^2	17.6	28.1	+10.5	>95%
	n	53	52	-	
Location 2 NB	$\bar{x}$	39.3	37.7	-1.6	94%
	σ	3.5	3.8	-	
	σ^2	12.3	14.4	+2.1	<95%
	n	44	34	-	
Location 2 SB	$\bar{x}$	38.7	39.7	+1.0	82%
	σ	4.6	3.0	-	
	σ^2	21.2	9.0	+12.2	>95%
	n	67	41	-	
Location 3 NB	$\bar{x}$	42.1	37.2	-4.9	>99%
	σ	4.2	5.1	-	
	σ^2	17.6	26.0	+8.4	<95%
	n	37	55	-	
Location 3 SB	$\bar{x}$	42.4	40.2	-2.2	>99%
	σ	3.8	4.5	-	
	σ^2	14.4	20.3	+5.9	<95%
	n	46	65	-	

were mixed. Significant decreases in speed variance occurred at Location 2, northbound under dry conditions and at Location 2, southbound during rain. Location 1, southbound during rain had a significant increase in variance (Figure 6).

FIGURE 6

EFFECT OF SRPM's ON SPEED VARIANCE AT RT. 35



DISCUSSION AND SUGGESTED RESEARCH

Raised pavement markers can be successful in reducing erratic maneuvers and traffic conflicts by altering the variable behavior of traffic with regard to lane placement, choice of exit pathway, and vehicle speeds. Although insufficient lengths of road were marked in order to perform an accident analysis, the reduction of erratic maneuvers accomplished infers the safer use of roadways. Alexander and Lunenfeld (5) describe erratic maneuvers as noncatastrophic system failures on a scale which includes accidents as catastrophic failures. They further state that "erratic maneuvers are sumptomatic of driver uncertainty at the navigational level and may cause serious problems for the traffic stream." It is not unreasonable to assume that most or all accidents are preceeded by some erratic maneuver, or that such a maneuver apparently inconsequential in the absence of other vehicles may be disasterous when performed with other cars around. Hence, the reduction of erratic maneuvers can be an indicator of a safer and more efficient utilization of the roadway.

The types of erratic maneuvers reduced by the presence of raised markers were: painted gore encroachments, center line and edge line encroachments, and lane weaving. Fewer gore encroachments should reduce instances of collisions with the physical gore and reduce conflicts between vehicles already in the deceleration lane and those exiting late through the gore. It is interesting that one site experienced a significant decrease in gore encroachments at traffic volumes of 500 vehicles/hour/lane, but no change in the erratic maneuver rate when twice that many vehicles were on the road. Possible reasons are: vehicles themselves can block the view of the markers, preventing following cars from reacting to the treatment; or as volumes increase, vehicles in a queue may follow a lead car into the exit rather than react to the markers. The potential for head-on accidents should be reduced when the number of vehicles encroaching on the opposing lane is decreased. On roads with little or no shoulder, reducing the edge line encroachments may cause a decrease in fixed object accidents. There is a concern in some circles that edge line markings may cause motorists to think there is a lane to the right of the edge line perhaps coercing motorists to drive off the road. The results of the study point to the opposite view, showing a reduction of vehicles traveling over the edge line.

Wet weather data was collected at two sites before and after the markers were installed. At one exit, Route 168, the rate of gore encroachments during rain was not significantly affected by the markers. However, at the time of data collection, traffic volumes were at the higher rate previously discussed and the failure of the markers to reduce gore encroachments may be due to the inability of the motorist to view the devices or vehicles in a queue following the lead car. At the second site, a left side exit with two exiting lanes, the percentage of vehicles changing lanes or encroaching on the other lane was significantly higher during rain without the markers, but not significantly different from dry conditions when the markers were placed. This is important documented evidence that raised markers provide significant guidance to motorists under adverse weather conditions when the visibility of painted lines is severely reduced.

The fact that the markers caused reductions in erratic maneuvers at lit and unlit sites was an unexpected occurrence. This result occurred for each type of site -- curves, exits, and bifurcations. This suggests that the treatment of areas with overhead lighting such as intersections and interchanges can provide a safety benefit to motorists and should not be excluded from consideration for the sole reason that they are lit.

Due to the expense of installing snowplowable raised pavement markers, decisions have to be made about where and when the markers should be used. Whether spot treatments of locations which are considered hazardous or entire roads should be marked could be the subject of future research, perhaps considering the cost benefit ratio of each situation. Research may also be useful in choosing between using the markers on interstates and primary level highways or two lane rural roads. Although the former would most likely have a higher VMT per lane mile of marked roadway, the dark winding nature of many rural roads and the presence of fixed obstacles near the roadway may point to their being considered a higher priority.

APPENDIX A

TABLE 9

DATA - EXITS

	2 Axle Vehicles				3+ Axle Vehicles		
Rt. 295 & 168	Total	Exits	Zone 1 Exits	Gore Enc.	Total	Exits	Gore Enc.
BEFORE							
11/16/78	2607	297	482 axles*	12	145	5	7
11/21/78	2811	307	440 axles	5	152	8	2
12/ 7/78	2659	279	432 axles	10	160	7	6
11/17/78 (Rain)	2738	295	328 axles	15	125	6	6
AFTER							
11/19/79	2406	300	418 axles	9	140	6	6
11/20/79	1036	120	140 axles	3	69	1	0
12/ 7/79	4003	449	602 axles	9	169	9	2
11/13/79 (Rain)	2397	309	356 axles	14	137	11	8
Rt. 295 & 38							
BEFORE							
10/30/78	1306	327	302	20	141	6	12
11/ 1/78	1323	346	326	13	167	7	23
11/ 2/78	1306	353	325	19	136	6	31
AFTER							
10/30/78	1026	325	293	7	135	5	2
11/ 5/79	1225	314	294	0	158	5	7
11/ 7/79	1335	354	310	5	135	8	4
Rt. 1 & 95							
BEFORE							
11/13/78	945	52	45	33	13	1	4
11/14/78	746	44	38	26	13	0	1
11/15/78 (Rain)	938	49	48	14	8	0	0
	1691	96	83	59	26	1	5
AFTER							
12/ 3/79	946	52	44	4	8	0	0
12/ 4/79	937	56	54	9	11	4	1

*Lack of a suitable place to observe the Zone 1, Zone 2 border resulted in the mechanical counting of this maneuver. The axle counts cannot be directly converted into 2-axle vehicles since an unknown number of the exiting trucks made this maneuver.

TABLE 10

DATA - EXITS

	2 Axle Vehicles				3+ Axle Vehicles		
	Total	Exits	Zone 1 Exits	Gore Enc.	Total	Exits	Gore Enc.
Rt. 440 & GSP							
BEFORE							
11/28/78	1362	586	72	18	51	1	0
11/29/78	1239	526	74	12	43	1	0
11/30/78	1438	623	60	12	63	1	1
AFTER							
11/27/79	1360	564	95	7	40	0	0
11/28/79	1426	570	118	5	56	1	3
11/29/79	1296	615	131	5	34	0	0
Rt. 440 & 9							
BEFORE							
11/28/78	1702	333	257	9	70	16	3
11/29/78	1534	287	210	10	55	12	0
11/30/78	1798	335	247	27	78	16	0
AFTER							
11/27/79	1729	360	237	11	54	11	1
11/28/79	1807	370	205	13	77	21	2
11/29/79	1715	407	281	15	53	19	2
Rt. 295 & 561							
BEFORE							
11/14/78	2649	597	542	17	154	5	3
11/16/78	2622	557	544	10	184	15	11
11/15/78 (Rain)	2657	557	517	42	183	9	7
AFTER							
11/16/79	2713	524	474	15	189	14	3
12/ 4/79	2371	551	510	12	168	11	6
12/ 5/79	2424	519	477	24	190	11	6

TABLE 11

DATA - EDGELINE STUDY

	2 Axle Vehicles				3+ Axle Vehicles		
	Total	Exits	Zone 1 Exits	Gore Enc.	Total	Exits	Gore Enc.
Rt. 440 & GSP							
BEFORE							
9/12/79	1487	522	40	11	83	0	0
9/18/79	1281	467	39	12	65	3	0
MIDDLE							
10/17/79	1481	489	84	6	67	0	0
10/18/79	1415	496	150	5	82	5	2
AFTER							
11/15/79	1061	378	68	4	58	0	0
Rt. 295 & 168							
BEFORE							
9/11/79	2151	274	362 axles*	16	248	15(69 axles)	2
9/12/79	2570	325	494 axles	22	279	16(75 axles)	4
MIDDLE							
10/11/79	1726	226	386 axles	3	172	9(41 axles)	2
10/15/79	2104	295	500 axles	5	237	12(59 axles)	6
AFTER							
11/14/79	1702	215	300 axles	8	216	8(39 axles)	3
11/19/79	2340	325	430 axles	3	289	21(99 axles)	7
Rt. 287 & 78							
BEFORE							
9/10/79	601	49	39	3	48	0	0
9/11/79	702	53	38	1	53	0	0
9/13/79	733	59	46	6	50	0	0
9/18/79	749	55	38	4	42	1	0
	2785	216	161	14	193		

*Lack of a suitable place to observe the Zone 1, Zone 2 border resulted in the mechanical counting of this maneuver. The axle counts cannot be directly converted into 2-axle vehicles since an unknown number of the exiting trucks made this maneuver.

TABLE 12

DATA - EDGELINE STUDY

	2 Axle Vehicles				3+ Axle Vehicles		
	Total	Exits	Zone 1 Exits	Gore Enc.	Total	Exits	Gore Enc.
Rt. 287 & 78 MIDDLE							
10/11/79	743	65	59	1	57	0	2
10/15/79	652	48	39	1	37	0	0
10/16/79	662	67	65	3	32	0	1
10/17/79	672	56	49	1	52	0	1
AFTER							
11/27/79	747	66	60	1	56	0	1
11/28/79	792	49	44	2	47	0	3
11/29/79	734	70	58	2	49	0	1
12/ 3/79	663	37	35	2	30	0	1

DATA - WEAVING STUDY

	Total	Exits	Exit Weaves	Gore Enc.	Total	Exits	Gore Enc.
Rt. 29 & Market BEFORE							
11/30/78	766	308	165	5	3	1	0
12/ 5/78	788	291	170	6	1	1	0
12/ 6/78	829	340	193	7	2	2	0
11/29/78 (Rain)	310	139	100	1	3	1	0
	[illegible]	[illegible]	[illegible]	18	[illegible]	[illegible]	[illegible]
AFTER							
11/ 8/79	580	270	104	3	3	1	0
11/14/79	597	290	107	4	3	2	0
11/16/79	703	381	154	6	3	1	0
11/13/79 (Rain)	725	308	134	8	4	3	0

TABLE 13

DATA - CURVES

2 Axle Vehicles							3+ Axle Vehicles	
Site	NB Total	Centerline Enc.	Edgeline Enc.	SB Total	Centerline Enc.	Edgeline Enc.	Total	Enc.
Rt. 206 BEFORE								
10/30/78	376	1	-	271	45	-	16	3
11/ 3/78	424	0	-	408	56	-	10	4
11/ 9/78	382	0	-	365	61	-	6	1
AFTER								
10/31/79	333	0	-	297	8	-	10	3
11/ 1/79	391	0	-	336	9	-	14	3
11/ 5/79	390	0	-	339	17	-	19	3
Rt. 29 BEFORE								
10/30/78	235	2	16	149	18	0	16	3
11/ 1/78	282	0	31	183	15	0	17	1
11/ 2/78	249	1	24	145	21	0	16	4
11/ 3/78	306	0	36	198	24	0	15	3
AFTER								
11/ 5/79	196	0	7	138	8	0	11	2
11/ 7/79	203	1	13	123	6	0	11	0
11/ 8/79	210	2	6	145	18	0	14	5
Rt. 29(Control) BEFORE								
11/ 6/78	229	3	1	145	0	15	11	3
11/ 8/78	229	4	0	150	0	11	17	8
11/ 9/78	249	7	0	155	0	10	22	1

TABLE 14

DATA - CURVES

	2 Axle Vehicles						3+ Axle Vehicles	
Site	NB Total	Centerline Enc.	Edgeline Enc.	SB Total	Centerline Enc.	Edgeline Enc.	Total	Enc.
Rt. 29(Control) AFTER								
11/15/79	215	3	0	145	0	7	19	3
11/20/79	215	8	0	136	0	8	15	1
11/30/79	303	6	0	176	0	17	13	2

DATA - BIFURCATIONS

	2 Axle Vehicles				3+ Axle Vehicles	
Site	Left Fork	Gore Enc.	Right Fork	Gore Enc.	Total	Enc.
Rt. 287 BEFORE						
11/ 1/78	487	17	690	16	157	4
11/ 2/78	498	7	721	11	139	4
11/ 3/78	739	15	848	30	148	4
AFTER						
12/ 3/79	437	1	627	2	142	2
12/ 5/79	485	4	603	4	123	2
12/ 7/79	650	2	742	9	112	0
Rt. 1 & 1A BEFORE						
11/ 8/78	590	0	642	39	21	0
11/ 9/78	559	4	732	54	22	0
11/13/78	536	5	615	33	15	0
AFTER						
11/ 7/79	489	10	599	14	18	0
11/ 8/79	547	5	590	7	27	0
11/ 9/79	553	5	668	19	13	0

APPENDIX B

FIGURE 7
MARKER TREATMENTS AT EXITS WITH DECELERATION LANES

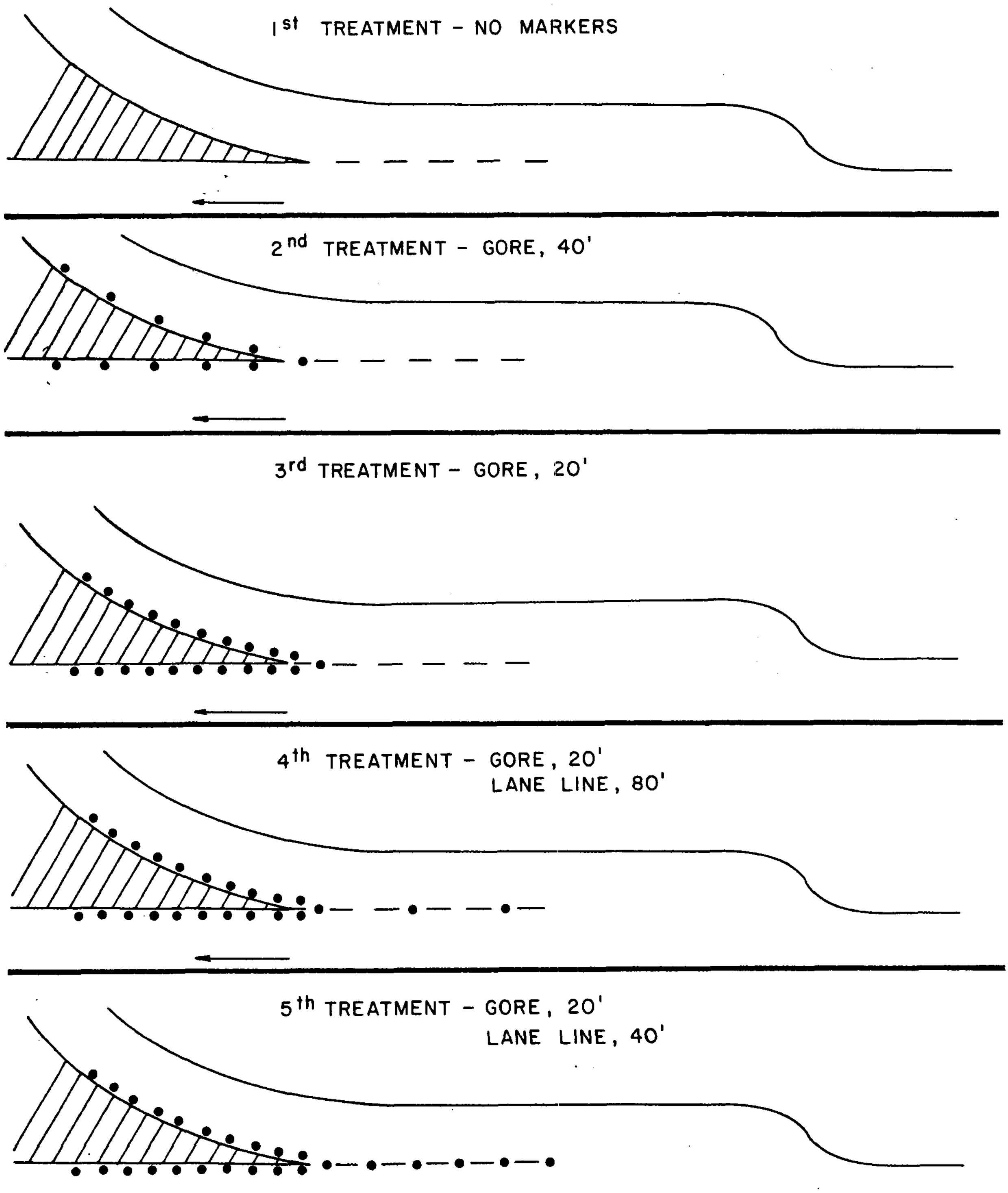


FIGURE 8

MARKER TREATMENTS AT EXITS WITH DECELERATION LANES

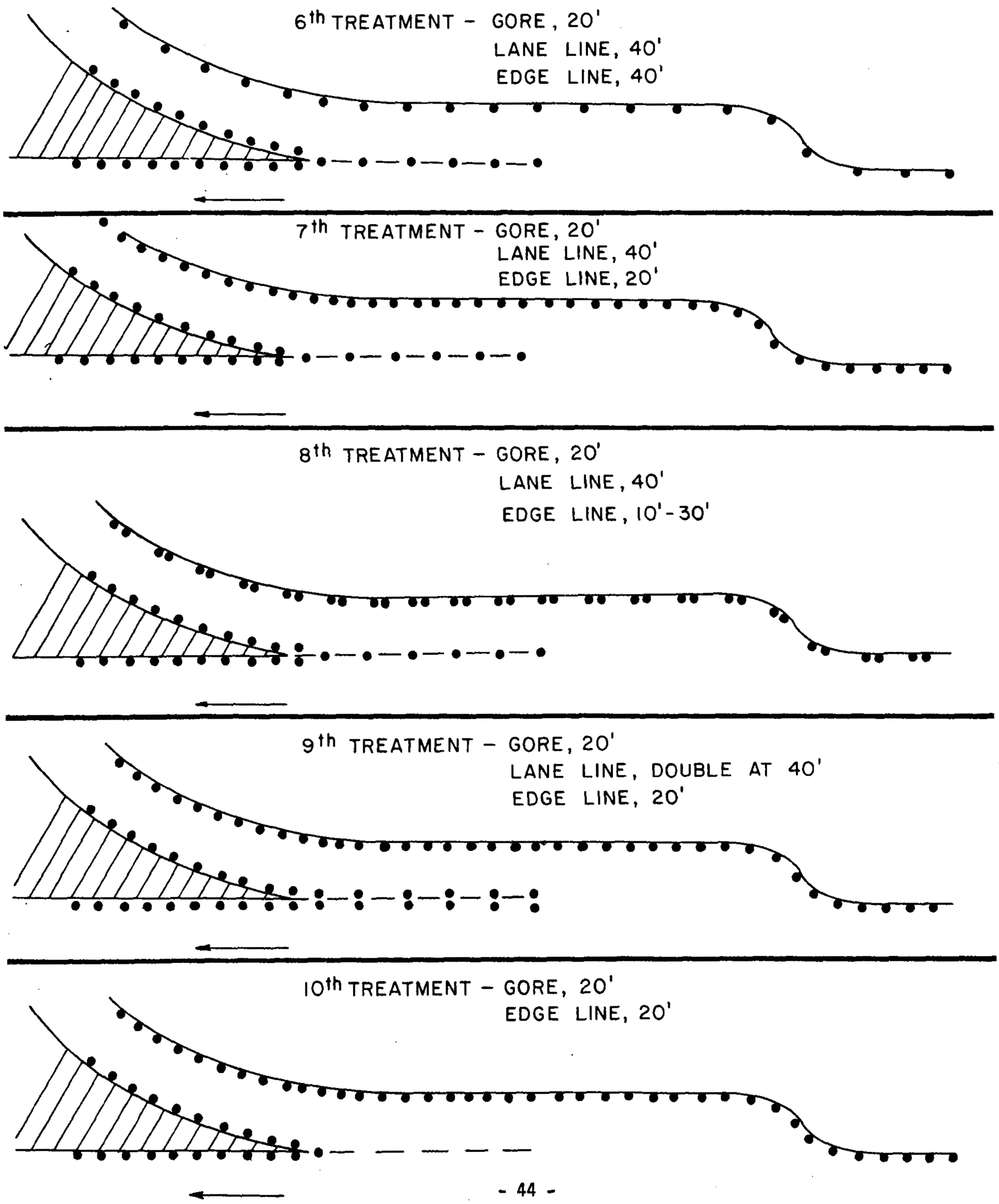
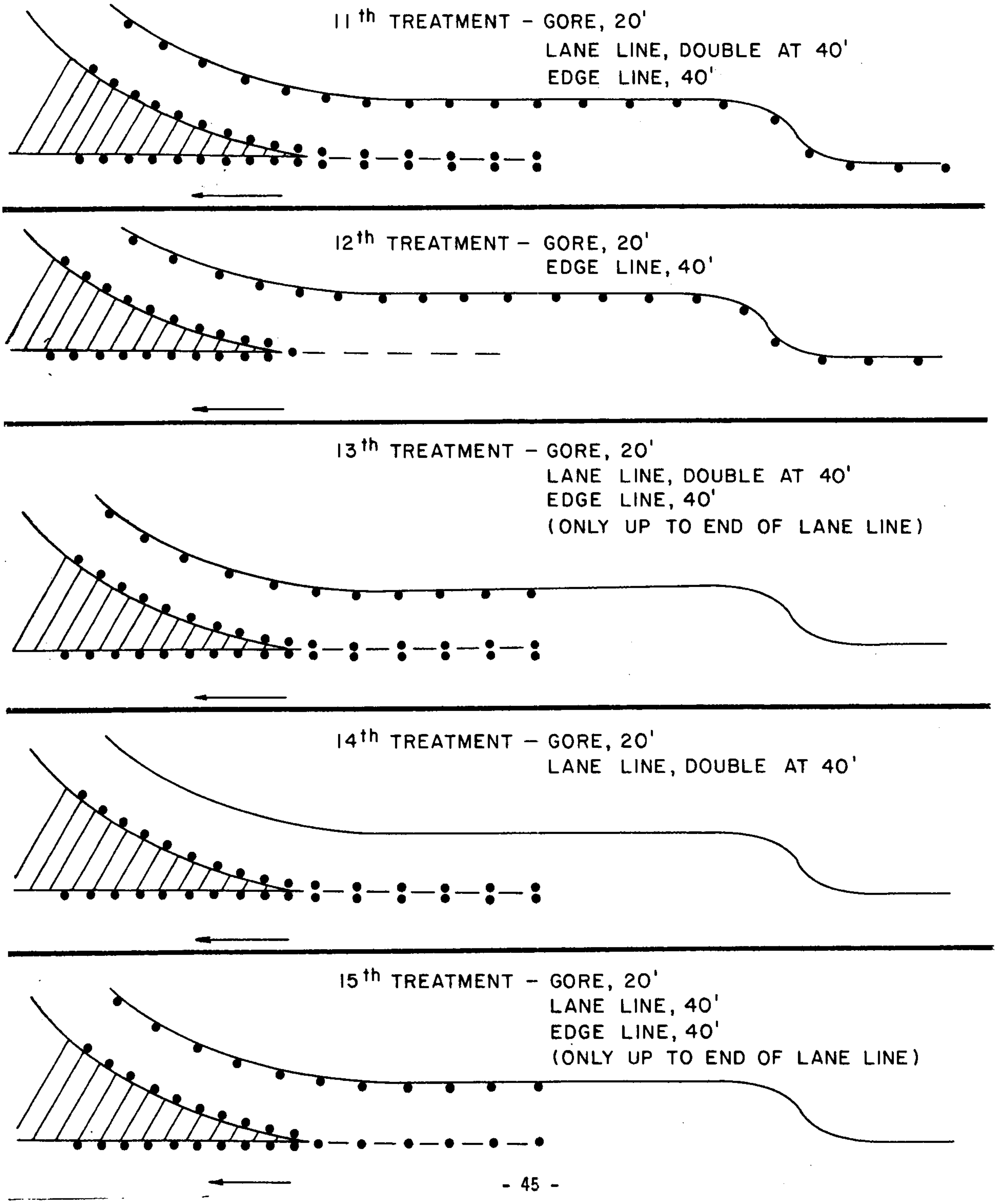


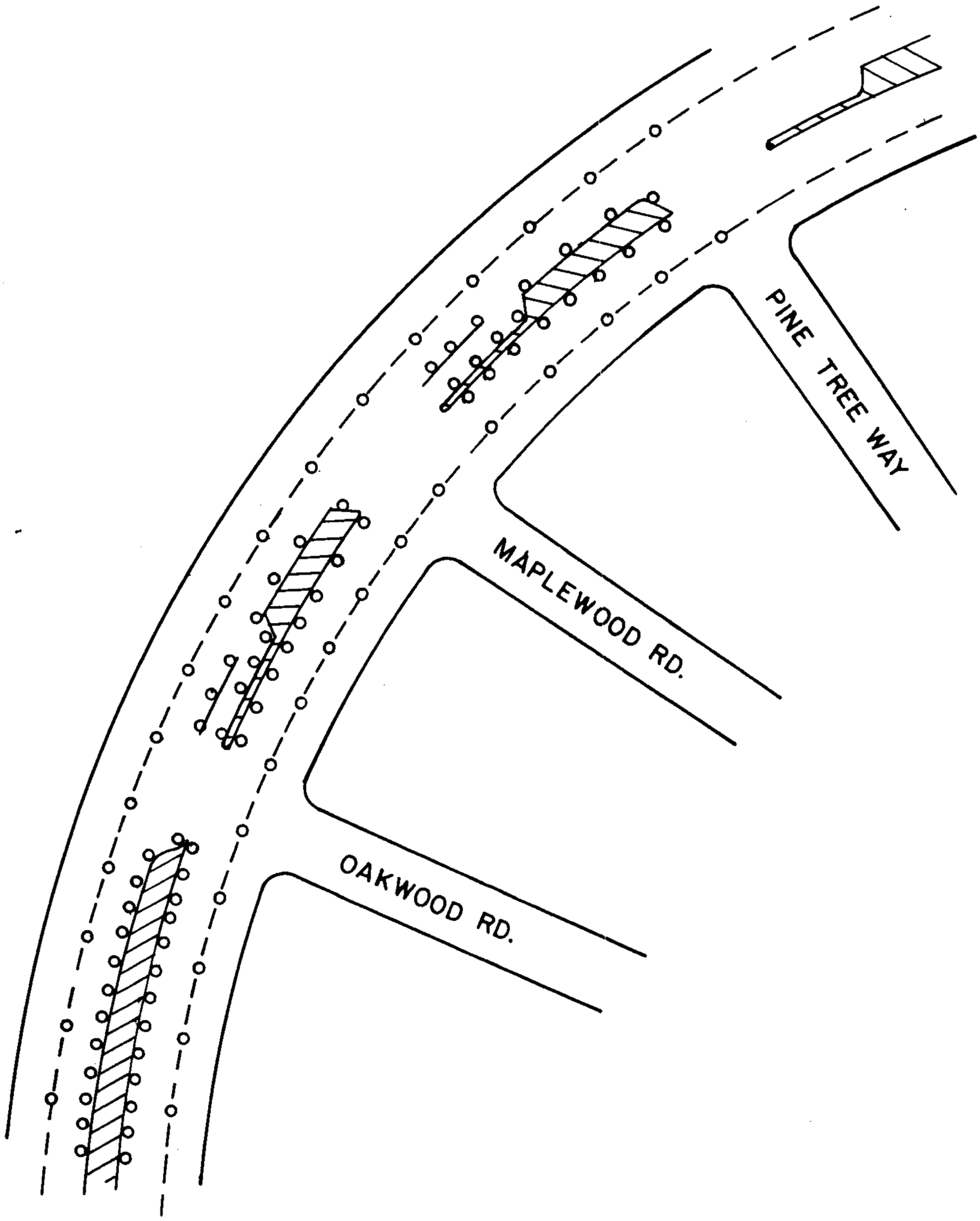
FIGURE 9

MARKER TREATMENTS AT EXITS WITH DECELERATION LANES



APPENDIX C

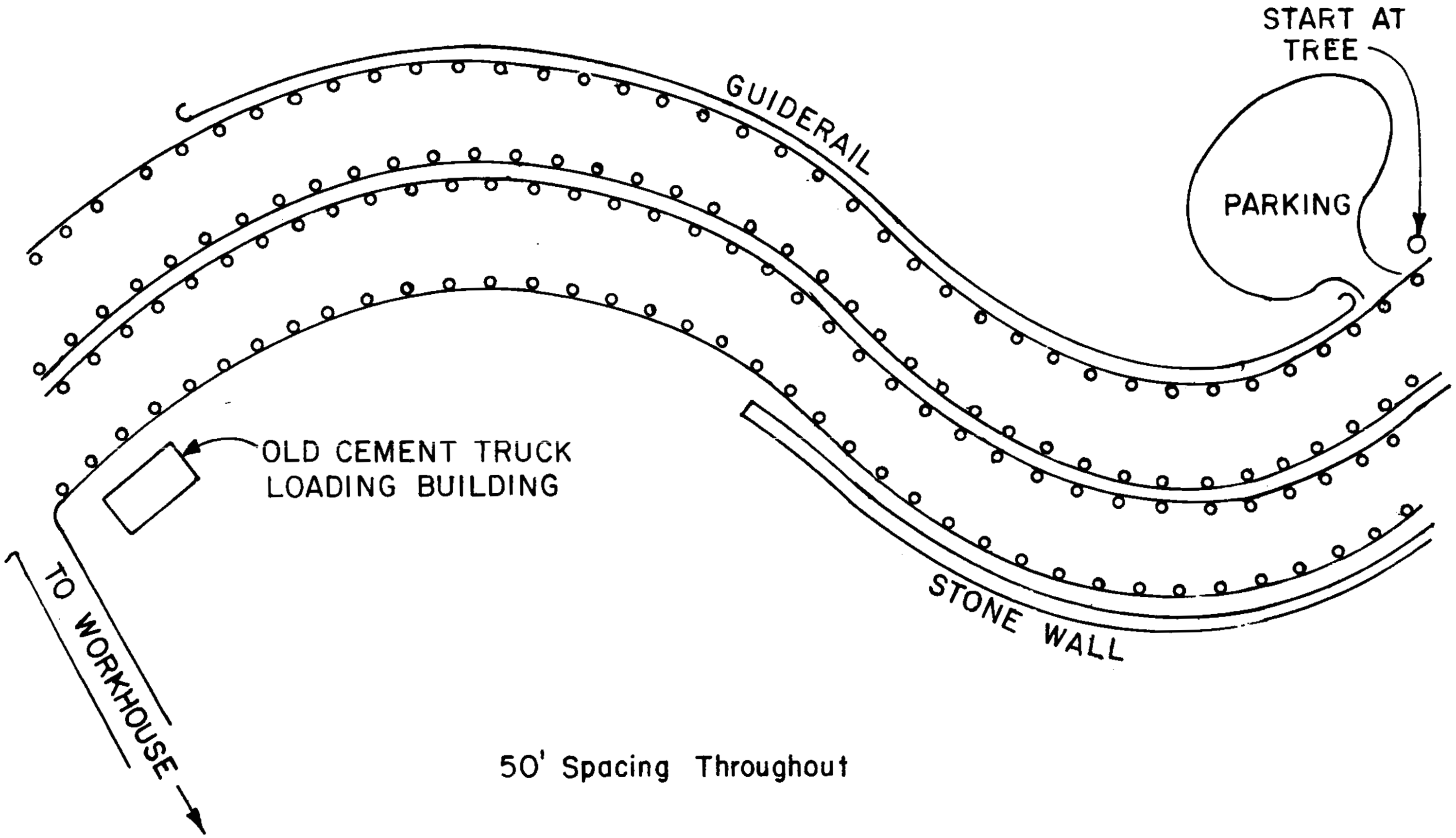
RT. 35, BELMAR - M.P. 20.6 TO 20.9



80' Spacing on the Lane Lines

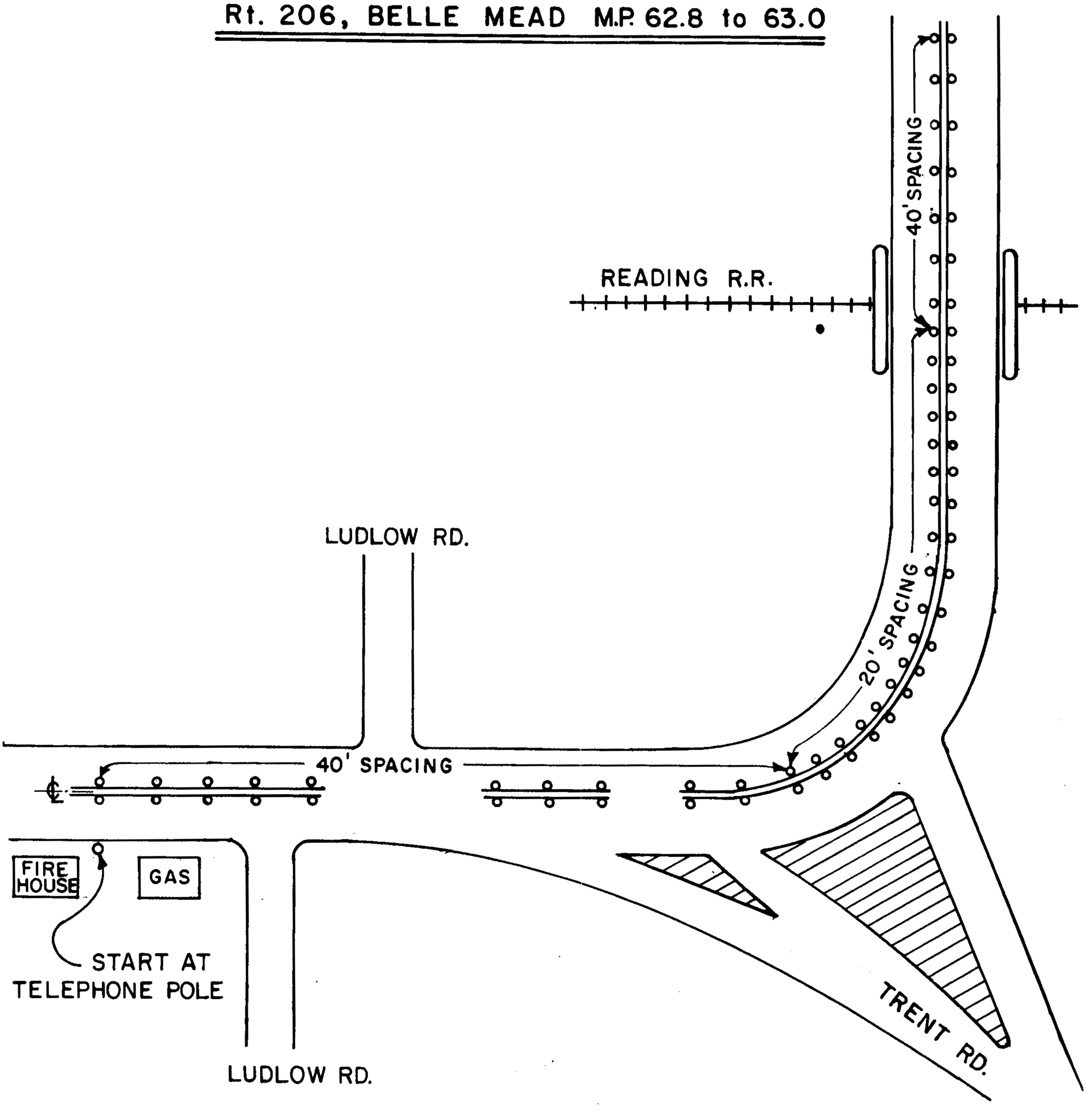
40' Spacing on the Center Lines

Rt. 29, Hopewell Near Workhouse M.P. 12.5 — 13.0

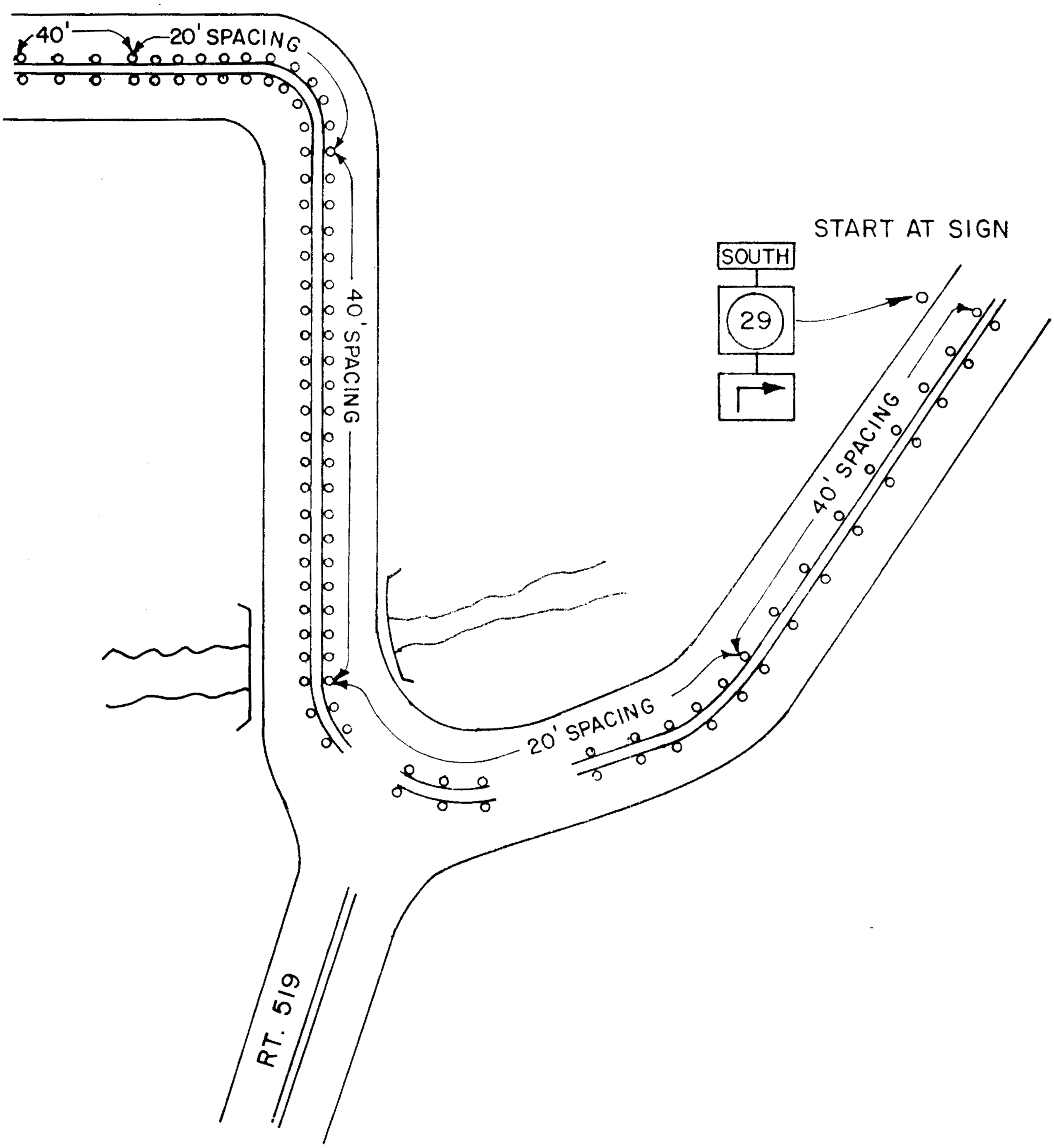


50' Spacing Throughout

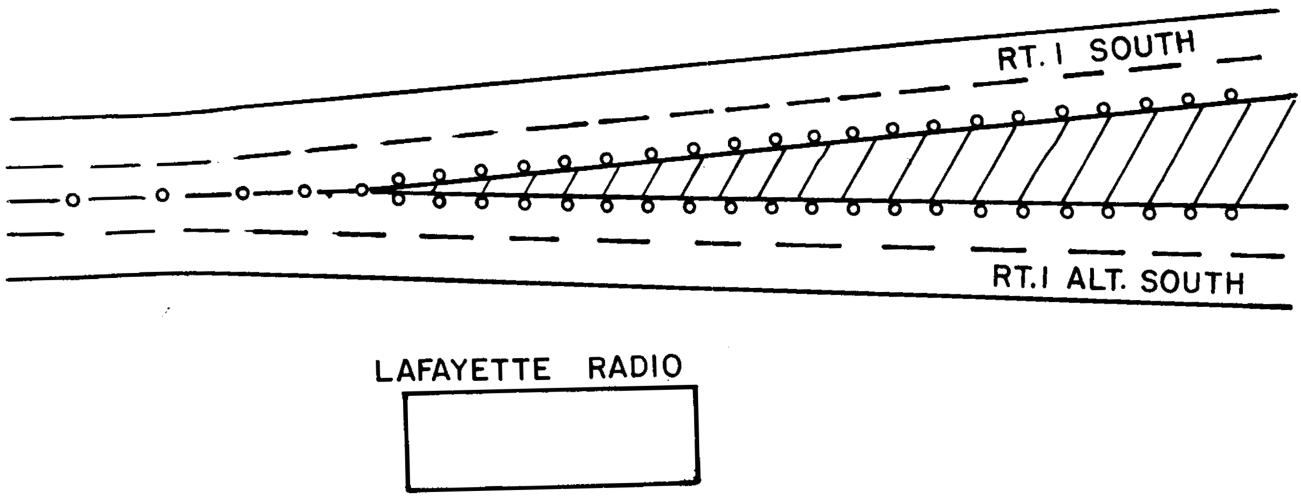
Rt. 206, BELLE MEAD M.P. 62.8 to 63.0



RT. 29, DELEWARE TWP. (NORTH OF STOCTON) M.P. 19.6-19.9



Rt. I South at Split With Rt. I Alternate, Lawrence M.P. 5.0

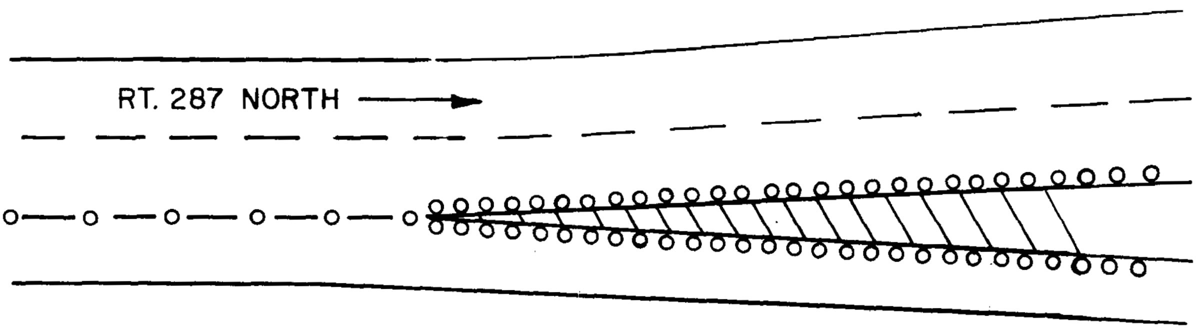


40' Spacing on Lane Line

20' Spacing on Gore

ROUTE 287 NORTH WHERE ROAD BECOMES DUALIZED

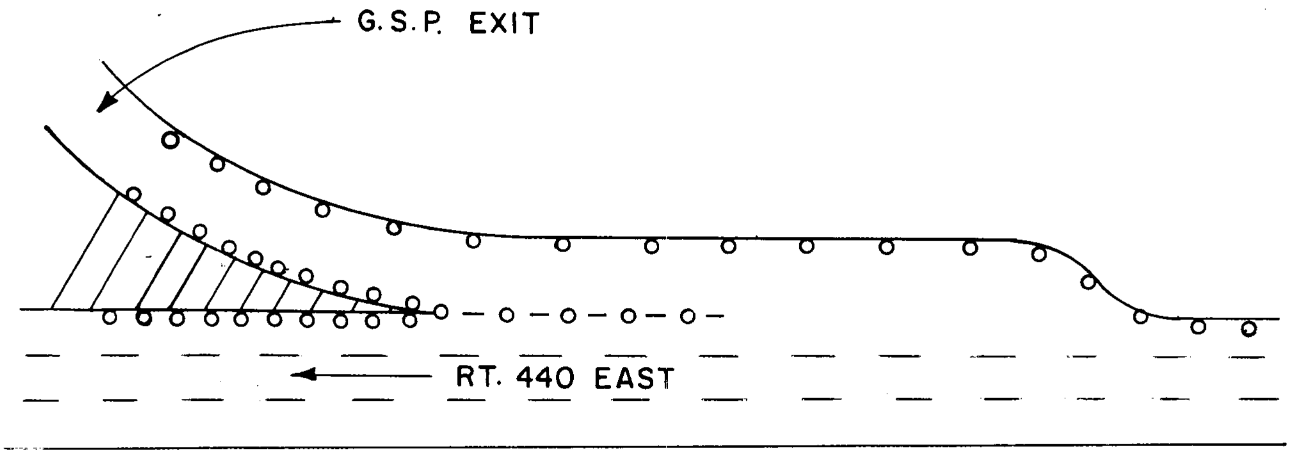
BRIDGEWATER TWP. M.P. 17.6



40' SPACING ON LANE LINES

20' SPACING ON GORE

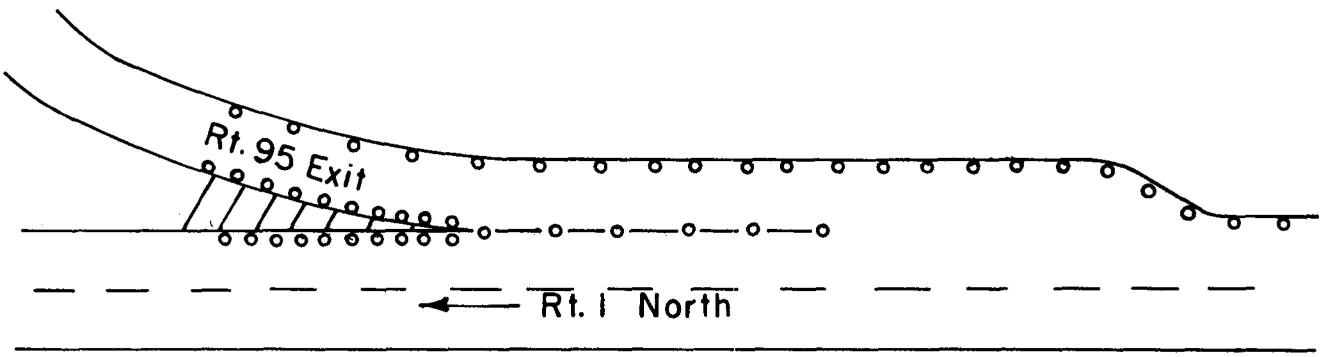
RT. 440 EAST AT G.S.P. EXIT, WOODBRIDGE TWP., M.P. 1.9



40' SPACING ON LANE LINE AND CURB OR EDGE LINE

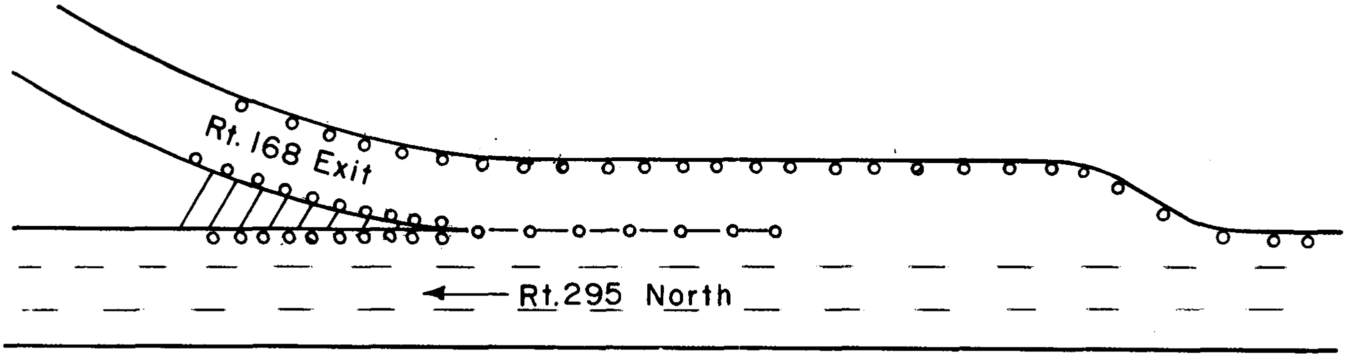
20' SPACING AT THE GORE

RT. I NORTH AT RT. 95 SOUTH EXIT, LAWRENCE M.P. 6.9



20' Spacing on Gore
40' Spacing on Laneline and
Curb or Edgeline

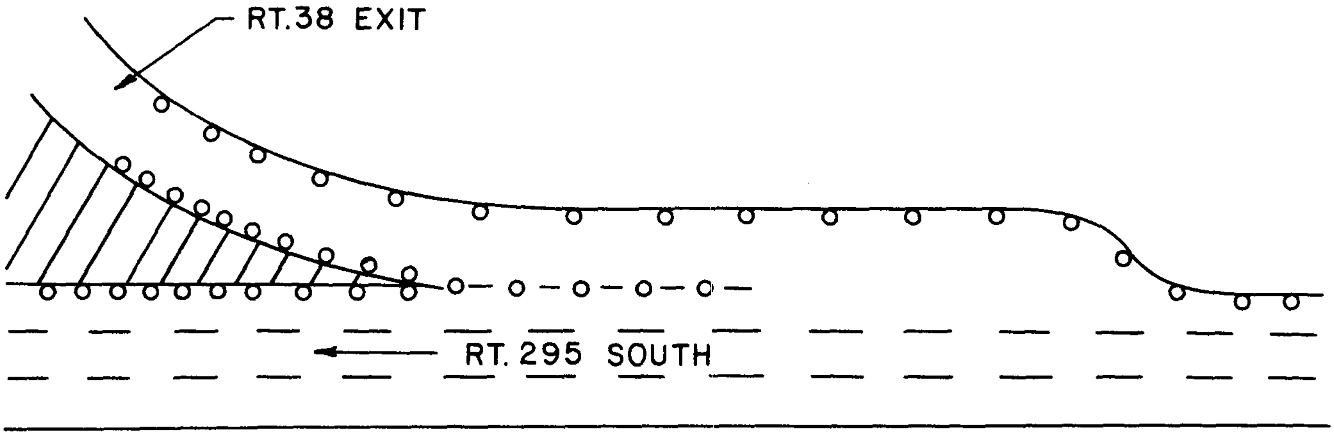
Rt. 295 NORTH AT RT. 168 EXIT, MT. EPHRAIM M.P. 28.0



20' Spacing on Painted Gore

40' Spacing on Lane Line and Curb or Edge Line

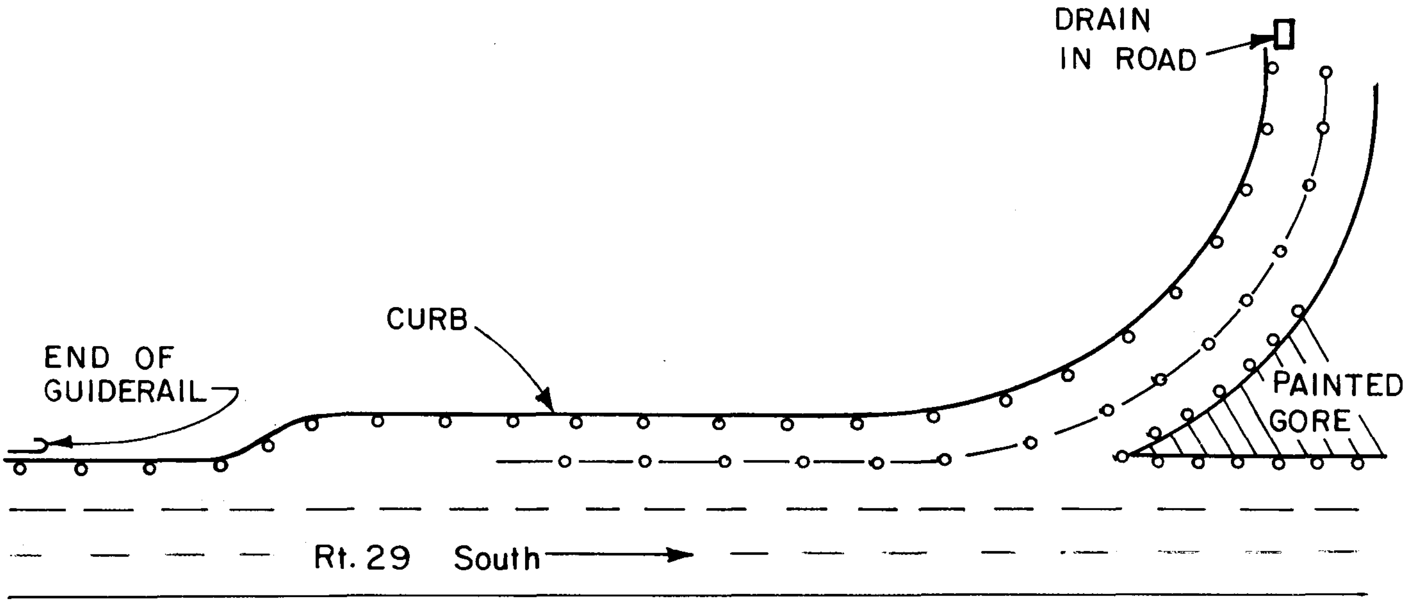
RT. 295 SOUTH AT RT. 38, MT. LAUREL TWP., M.P. 40.7



40' SPACING ON LANE LINE AND CURB OR EDGE LINE

20' SPACING AT THE GORE

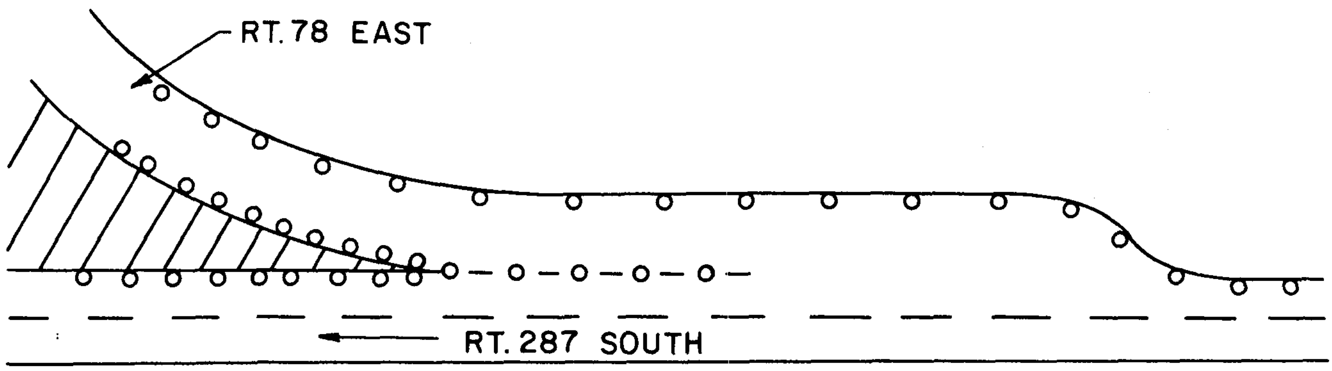
RT. 29 SOUTH AT MARKET STREET EXIT TRENTON M.P. 0.4



20' Spacing on the Gore

40' Along Curb and on Lane Line

RT. 287 SOUTH AT RT. 78, BEDMINSTER TWP., M.P. 16.9



40' SPACING ON LANE LINE AND CURB OR EDGE LINE

20' SPACING AT THE GORE

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