ACKNOWLEDGMENT

Considerably more detail on the research reported on herein can be found in the final report, submitted to the Federal Highway Administration (FHWA) (6). The research was funded by FHWA and undertaken at the Maine facility with staffing from FHWA, the Maine DOT, and the Social Science Research Institute of the University of Maine at Orono. The contributions of that staff notwithstanding, the responsibility for the conclusions presented here and in the final reports and any errors therein rest with me and are not necessarily those of FHWA, Maine DOT, or the University of Maine.

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Effect of Raised Pavement Markers on Traffic Performance

WILLIAM L. MULLOWNEY

This project measured and documented the effect that snowplowable raised pavement markers (SRPMs) 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 included erratic maneuvers such as cutting through painted gores, lane changes or encroachments, center and edgeline encroachments, point of entrance into deceleration lanes, and mean speeds and speed variance at curves. All erratic maneuvers studied were reduced significantly at various sites for traffic volumes per lane of up to 500 vehicles/h. At volumes per lane of between 900 and 1000 vehicles/h 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, which resulted in less abrupt speed changes. The effect of SRPMs on speed variance was inconclusive. The markers were effective in reducing erratic maneuvers at sites with and without overhead lighting. At one site a significantly higher rate of erratic maneuvers during rain conditions before the markers were placed was not only severely reduced but the wet condition erratic maneuver rate approached the quality of the dry condition rate when markers were present.

This study was undertaken to determine whether snowplowable raised pavement markers (SRPMs) 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. The general belief is that the delineation provided by SRPMs would increase the driver's view of road and exit geometry and assist him or her in choosing a safe and efficient pathway.

OBJECTIVES

The study was designed to achieve the following objectives:

1. To measure the effect of SRPMs on centerline and edgeline encroachments on both lit and unlit curved sections of highway;
2. To measure the effect of SRPMs on speeds and speed variances on lit and unlit curves;
3. To measure the effect of SRPMs on the incidence of drivers encroaching on painted gores, both at exits and at highway bifurcations; and
4. To see whether SRPMs would cause motorists to enter the deceleration lanes at exits more consistently.

INSTALLATION PROCEDURE

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 the safety operation, a water truck, and sufficient workers to assist in placing the markers.

STUDY DESIGN

Potential sites were selected on the basis of the following criteria.

1. Existance of higher than normal rates of run-off-the-road accidents for a short section of highway;
2. Existance 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 SRPMs;

4. Suitability of observation points for manual data collection;
5. Suitability of data collection by mechanical and photographic techniques;
6. Sufficient traffic volumes after dark to collect enough data for statistical analysis;
7. Distance from the research office, a concern for collection of data under rain conditions;
8. Lack of potential vandalism of markers and mechanical counting devices based on the accessibility of the site to pedestrians and whether the site is located in a developed area; and
9. Existence or lack of street lighting.

Pilot Studies at Potential Study Sites

A night time 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 follows:

Centerline encroachment--any wheel of the vehicle crossed over both yellow lines and encroached on the opposing lane of travel;

Edgeline encroachment--any wheel of the vehicle crossed over the white edgeline and encroached on the shoulder;

Gore encroachment--any wheel of the vehicle touched 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 zone 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 touched zone 1, it was considered a zone 1 exit;

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

Vehicle speed--spot speeds were collected at select 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 were decided during the pilot studies.

Data Collection Method

Most of the data were collected manually by observers at each site. Observation points that allowed the observer to be raised up (preferably over the roadway) and hidden from view were used. Such points were commonly on overpasses and railroad bridges. Where these did not exist, observers were stationed on the side of the road on an embankment. Where this was not available, 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. The deceleration lane was divided into two zones, with the division at half the total length of the lane.

At curves, centerline and edgeline 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 by using a visual and audio technique and traffic volumes were counted manually.

The audio technique involved running hoses from pneumatic traffic counters to the centerlines and edgelines of the curves studied and to the tip of the painted gore for the highway bifurcations. A car that encroached on the centerlines, edgelines, or gore would trip the counter to cause an audio signal that an observer stationed at the side of the road would record as an erratic maneuver (Figure 1).

Vehicles were classified into two-axle and three or more axle categories since it was believed that three or more axle vehicles would not react to the markers in the same manner as would two-axle vehicles.

Statistical Analysis

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

Test of Proportions

The equation for the test of proportions is as follows (1, pp. 176-178):

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

where

$p_1 = n_1/N_2$,
$p_2 = n_2/N_2$,
$p = (n_1 + n_2)/(N_1 + N_2)$,
$q = 1 - p$,
n_1 = number of before erratic maneuvers,
n_2 = number of after erratic maneuvers,
N_1 = traffic volume before, and
N_2 = traffic volume after.

This test was used to analyze the effect of SRPMs on gore encroachments, longitudinal exit placement, lane weaves, and centerline and edgeline encroachments. The test was applied (1, p. 117), "if the smaller value of p or q multiplied by the smaller value of N exceeds five." 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 decision, conclusions, and recommendations, a level of 95 percent or greater was considered significantly different for all statistical tests used.

t-Test

The t-test is calculated as follows (2, p. 200):

$$t = (\bar{X}_1 - \bar{X}_2)/\sqrt{(S_1^2/N_1) + (S_2^2/N_2)} \qquad (2)$$

$\bar{X}_1$ = mean of before sample,
$\bar{X}_2$ = mean of after sample,
S_1 = standard deviation of before sample,
S_2 = standard deviation of after sample,
N_1 = before samples, and
N_2 = after samples.

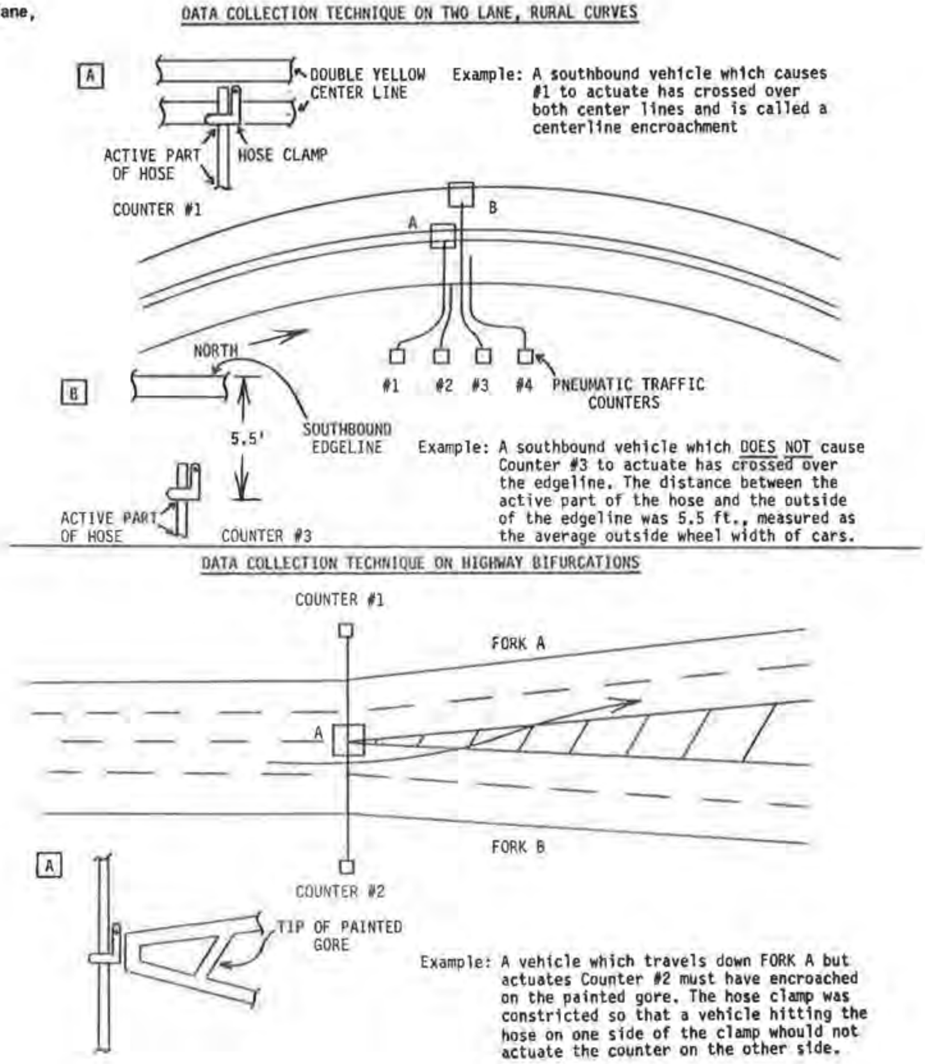
This test was used to analyze the differences in mean speeds attributable to the installation of the markers.

Table 1. Site descriptions and traffic performance measures studied.

Location	No. of Lanes	Lane Width (ft)	Shoulder Width (ft)	Gore Length (ft)	Deceleration Lane Length (ft)	Degree of Curve	Speed Limit (mph)	Lighting	Measures Studied[a]
Curves									
NJ-35	4 with 10-ft painted median	11	None			6	35	Yes	1
NJ-29	2	10	4			8	45	No	1,2,3
US-206	2	10	None			32	50	Yes	2
Bifurcations									
US-1 and US-1A	Right fork 2, left fork 2	12	10	400			55	Yes	4
I-287	Right fork 1, left fork 2	12	12	500			55	No	4
Exits									
NJ-440 and Garden State Parkway	3 thru, 1 right exit	12	10	142	410		55	Yes	4,6
US-1 and I-95	2 thru, 1 right exit	12	10	80	650		55	Yes	4,6
I-295 and NJ-168	3 thru, 1 right exit	12	None	170	830		55	Yes	4,6
I-295 and NJ-38	3 thru, 1 right exit	12	12	140	700		55	Yes	4,6
NJ-29 and Market St	3 thru, 2 left exits	13	None	88	730		50	Yes	4,5
I-287 and US-78	2 thru, 1 right exit	12	12	160	580		55	No	4,6
Control sites									
NJ-29	2	10	4			5	45	No	1,2,3
NJ-440 and US-9	3 thru, 1 right exit	12	10	134	480		55	Yes	4,6
I-295 and NJ-561	3 thru, 1 right exit	12	12	140	480		55	Yes	4,6

[a] 1 = speeds, 2 = centerline encroachments, 3 = edgeline encroachments, 4 = gore encroachments, 5 = lane changes or encroachments, and 6 = longitudinal exit placement.

Figure 1. Data collection technique on two-lane, rural curves and on highway bifurcations.



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.

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.

F-Test

The equation for the F-test is as follows (3, p. 131):

$$F = \sigma_1^2/\sigma_2^2 \qquad \begin{aligned} F_1 &= N_1 - 1\ \text{df} \\ F_2 &= N_2 - 1\ \text{df} \end{aligned} \tag{3}$$

where

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, and
N_2 = sample size used to compute σ_2.

The larger variance is designated σ_1^2 and is 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: TWO-AXLE VEHICLES

Effect of SRPMs on Erratic Maneuvers Through Painted Gore at Exits

Six of nine sites experienced statistically significant reductions in the percentage of cars that cut through the painted gore; the two control sites did not change significantly (Table 2). Two sites (NJ-29 and NJ-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.

NJ-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 exit lanes between which a considerable amount of lane changing took place. The effect of the markers on this maneuver is discussed later.

That the NJ-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 occurred. There was a large difference in the traffic volume per lane for the two different times of data collection--950 vehicles/h in the earlier period and 400 vehicles/h 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 ft for the earlier time and about 750 ft for the later period. The closer average spacing in the first condition may have diminished the ability of the motorist to view enough of the exit markers in order to recognize the pattern. This may account for the lack of response to the markers under the higher-volume condition.

Effect of SRPMs on Choice of Exiting Path

Data were collected at four study sites and two control sites to see whether the SRPMs would cause more drivers to exit earlier in the deceleration lane (Figure 2, treatments A and B). The percentage of exiting vehicles that exited in zone 1 was collected before and after the installation of the markers.

Although the percentage of exiting vehicles in zone 1 changed significantly for all study sites except US-1 and I-95 (Table 3), the fact that the control sites experienced significant changes of a similar magnitude prohibits assigning of responsibility for the changes to the application of SRPMs.

The results of the study on the addition of edgelines and their effect on choice of exiting path are also listed in Tables 3 and 4. One trend exists for the data. When the gore and lane line were marked (Table 4, treatment B), all three sites had an increase in the percentage of zone 1 exits. When edgeline markers were added (treatment C), all three sites had a decrease in the percentage of zone 1 exits when compared with treatment B.

Effect of SRPMs on Lane Changing or Encroachment Between Two Exit Lanes

The incidence of lane changing or encroachment between two exit lanes on a left exit was significantly reduced with the application of SRPMs in both wet and dry conditions. In the rain, when the maneuvers were more prevalent than in dry condition, the reduction was greater and the percentage of erratic vehicles in the rain (44 percent) approached the percentage of erratic vehicles in the dry condition (38 percent) when SRPMs were present (see table below).

NJ-29 Condition	Total Exits	Erratic Maneuvers	Percentage	Change (%)	Level of Significance (%)
Dry					
Before	939	528	56.2		
After	941	365	38.8	-17.4	>99
Rain					
Before	139	100	71.9		
After	308	134	43.5	-28.4	>99

Effect of SRPMs on Gore Encroachments at Highway Bifurcations

The percentage of vehicles that cut across the painted gore at bifurcations was drastically reduced both for a lit (US-1 and 1A, 400-ft gore) and unlit site (I-287, 500-ft gore). No control site was studied for comparison; however, the magnitude of the change given in the table below is a telling statistic.

Route	Total Vehicles	Gore Encroachments	Percentage	Change (%)	Level of Significance (%)
US-1 and US-1A					
Before	3674	135	3.67		
After	3446	60	1.74	-1.93	>99
I-287					
Before	3983	96	2.41		
After	3544	22	0.62	-1.79	>99

Effect of SRPMs on Encroachments at Two-Lane, Rural Curves

Centerline and edgeline encroachments were reduced at the study sites by significant amounts but at a control site encroachments changed by nonsignificant amounts (Table 5). Unaccountably, the change at US-206, which has a good deal of street lighting, was larger than at NJ-29, which has no lighting.

The importance of minimizing centerline encroachments is easily apparent. The reduction of edgeline encroachments might not seem as important because conflict with other vehicles is not likely to occur. However, on a road like NJ-29, which is dark, with trees and telephone poles within a couple of feet of the edgeline, reduction of this type of erratic maneuver may be considered beneficial.

RESULTS: THREE OR MORE-AXLE VEHICLES

As previously stated, three or more-axle vehicles were differentiated from two-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 and
2. Three or more axle vehicles have reduced maneuverability, which may inhibit their ability to react to SRPMs.

Table 2. Effect of SRPMs on gore encroachments.

Site	Before			After					
	Total Vehicles	Gore Encroachments	Percent	Total Vehicles	Gore Encroachments	Percent	Change (%)	Level of of Significance (%)	Vehicles per Hour per Lane
NJ-29[a]	2383	18	0.76	1880	13	0.69	-0.07	<50	250
NJ-29, rain[a]	310	1	0.32	725	8	1.10	+0.78	–[b]	250
US-1 and I-95[a]	1691	59	3.49	1883	13	0.69	-2.80	>99	450
I-295 and NJ-38[a]	3935	52	1.32	3586	12	0.33	-0.99	>99	450
NJ-440 and Garden State Parkway[a]	4039	42	1.04	4082	17	0.42	-0.62	>99	500
I-295 and NJ-168[a]	8077	27	0.33	7445	21	0.28	-0.05	<50	950
I-295 and NJ-168, rain[a]	2738	15	0.55	2397	14	0.58	+0.03	<50	950
NJ-440 and US-9[a,c]	5034	46	0.91	5251	39	0.74	-0.17	65	650
I-295 and NJ-561[a,c]	5271	27	0.51	7508	51	0.68	+0.17	79	900
NJ-440 and Garden State Parkway[d]	2781	23	0.83	3957	15	0.38	-0.45	98	250
I-295 and NJ-168[d]	4721	38	0.80	7872	19	0.24	-0.56	>99	400
I-287 and US-78, no lighting[d]	2785	14	0.50	5665	13	0.23	-0.27	>99	200

[a] Data were collected between 5:30 and 7:00 p.m.
[b] Insufficient data to apply statistical tests.
[c] Control site.
[d] Data were collected between 8:00 and 10:00 p.m.

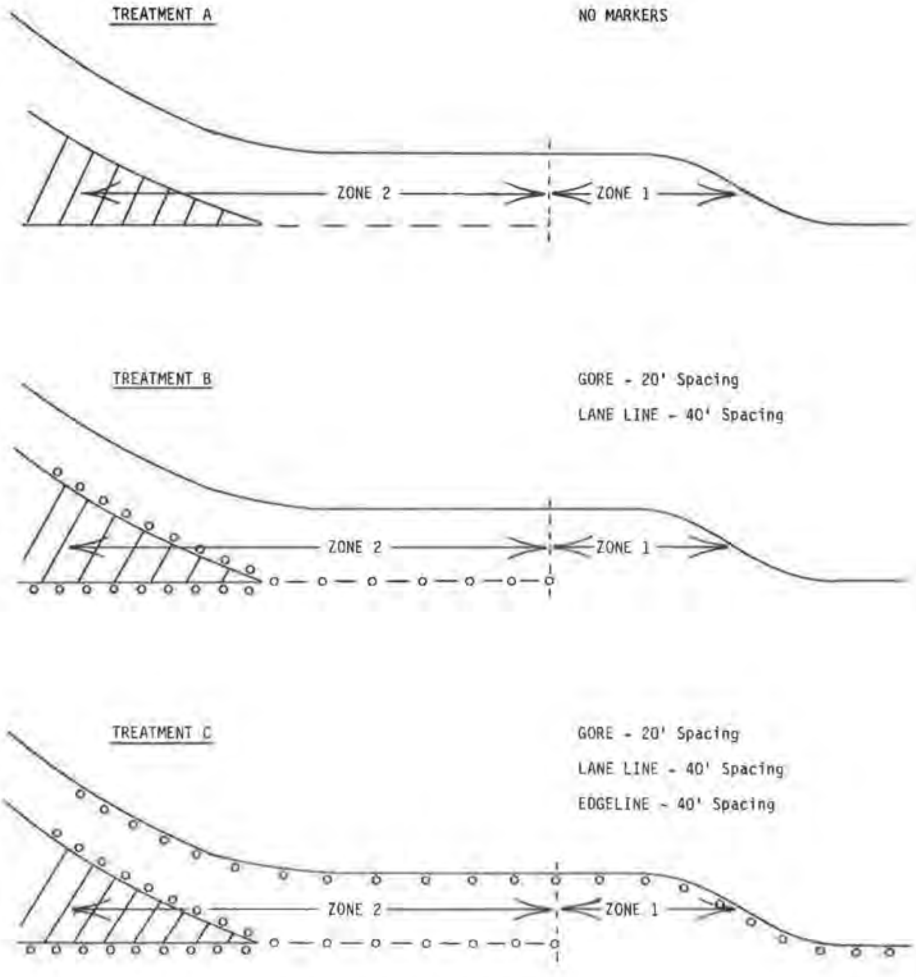


Figure 2. Marker layouts for longitudinal exit placement studies.

Sufficient data were 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 exist for applying the test were used in this analysis.

Table 6 shows the results of this analysis. Only one site, I-295 and NJ-38, experienced a change with a level of significance greater than 95 percent. Therefore, the general conclusion that SRPMs do not affect the traffic performance of three or more-axle vehicles with respect to the types of maneuvers studied can be reached.

RESULTS: EFFECT OF SRPMS ON VEHICLE SPEEDS AT CURVES

NJ-29, Hopewell

Speeds were collected at four locations in both the northbound and southbound directions. Location 1 was at the beginning of the south end of the installation, location 2 was at the apex of the curve, location 3 was at the north end of the installation,

Table 3. Percentage of two-axle exiting vehicles that enter first half (zone 1) of deceleration lane between 5:30 and 7:00 p.m.

	Before Treatment A			After Treatment C				
Sites	Exiting Vehicles	Exits in Zone 1	Percent	Exiting Vehicles	Exits in Zone 1	Percent	Change (%)	Level of Significance (%)
I-295 and NJ-168[a]	1876	1354	72.2	1823	1160	63.6	-8.6	>99
I-295 and NJ-38	1026	953	92.9	993	897	90.3	-2.6	96
US-1 and I-95	96	83	86.5	108	98	90.7	+4.2	65
NJ-440 and Garden State Parkway	1735	206	11.9	1749	344	19.7	+7.8	>99
NJ-440 and US-9[b]	955	714	74.8	1137	723	63.6	-11.2	>99
I-295 and NJ-561[b]	1154	1086	94.1	1594	1461	91.7	-2.4	98

[a] Data were compiled in axles, not vehicles. [b] Control site.

Table 4. Percentage of two-axle exiting vehicles that enter first half (zone 1) of deceleration lane between 8:00 and 10:00 p.m.

	Before Treatment A			Middle Treatment B			After Treatment C						
Site	Exits	Zone 1	Percent	Exits	Zone 1	Percent	Exits	Zone 1	Percent	Change, A to B (%)	Level of Significance	Change, B to C (%)	Level of Significance
NJ-440 and Garden State Parkway	989	79	8.0	985	234	23.8	378	68	18.0	+15.8	>99	-5.8	97
I-295 and NJ-168[a]	1342	856	63.8	1142	886	77.6	1218	730	59.9	+13.8	>99	-17.7	>99
I-287 and US-78[b]	216	161	74.5	236	212	89.8	232	197	84.9	+15.3	>99	-4.9	88

[a] Data were compiled in axles, not vehicles. [b] No lighting.

Table 5. Effect of SRPMs on centerline and edgeline encroachments by two-axle vehicles on two-lane rural curves.

	Before			After				
Site	Total Vehicles	Encroachments	Percent	Total Vehicles	Encroachments	Percent	Change (%)	Level of Significance (%)
Centerline encroachments								
US-206	1044	162	15.5	972	34	3.5	-12.0	>99
NJ-29[a]	675	78	11.6	406	32	7.9	-3.7	95
NJ-29[a,b]	707	14	2.0	733	17	2.3	+0.3	<50
Edgeline encroachments								
NJ-29[a]	1072	107	10.0	609	26	4.3	-5.7	>99
NJ-29[a,b]	450	36	8.0	457	32	7.0	-1.0	<50

[a] No lighting. [b] Control site.

Table 6. Effect of SRPMs on erratic maneuvers by vehicles (three or more axles).

	Before			After				
Site	Vehicles	Encroachments	Percent	Vehicles	Encroachments	Percent	Change (%)	Level of Significance (%)
Exit								
I-295 and NJ-168[a]	457	15	3.3	378	8	2.1	-1.2	68
I-295 and NJ-168, rain[a]	125	6	4.8	137	8	5.8	+1.0	<50
I-295 and NJ-38[a]	444	66	14.9	438	13	3.0	-11.9	99
I-295 and NJ-561[b]	338	14	4.1	547	15	2.7	-1.4	74
I-295 and NJ-168[c]	527	6	1.1	505	10	2.0	+0.9	71
Two-lane rural curves								
US-206[d]	32	8	25.0	43	9	20.9	-4.1	<50
NJ-29[d]	64	11	17.2	36	7	19.4	+2.2	<50
NJ-29[b,d]	50	12	24.0	47	6	12.8	-11.2	84
Bifurcations								
I-287	444	12	2.7	377	4	1.1	-1.6	91

[a] Data were collected during peak periods.
[b] Control site.
[c] Data were collected during off-peak periods.
[d] Includes centerline and edgeline encroachments.

and location 4 was about 1000 ft north of the installation, around a curve. At locations 1, 2, and 3 the markers were visible. Lack of a suitable place for parking the car out of the motorists' view prevented the collection of speeds at a control site south of the installation.

The SRPMs appear to have caused a smoother speed profile through the site in both the northbound and southbound directions (Figure 3, Table 7). This is evidenced by the smaller changes in speed that oc-

Figure 3. Effect of SRPMs on speed at NJ-29.

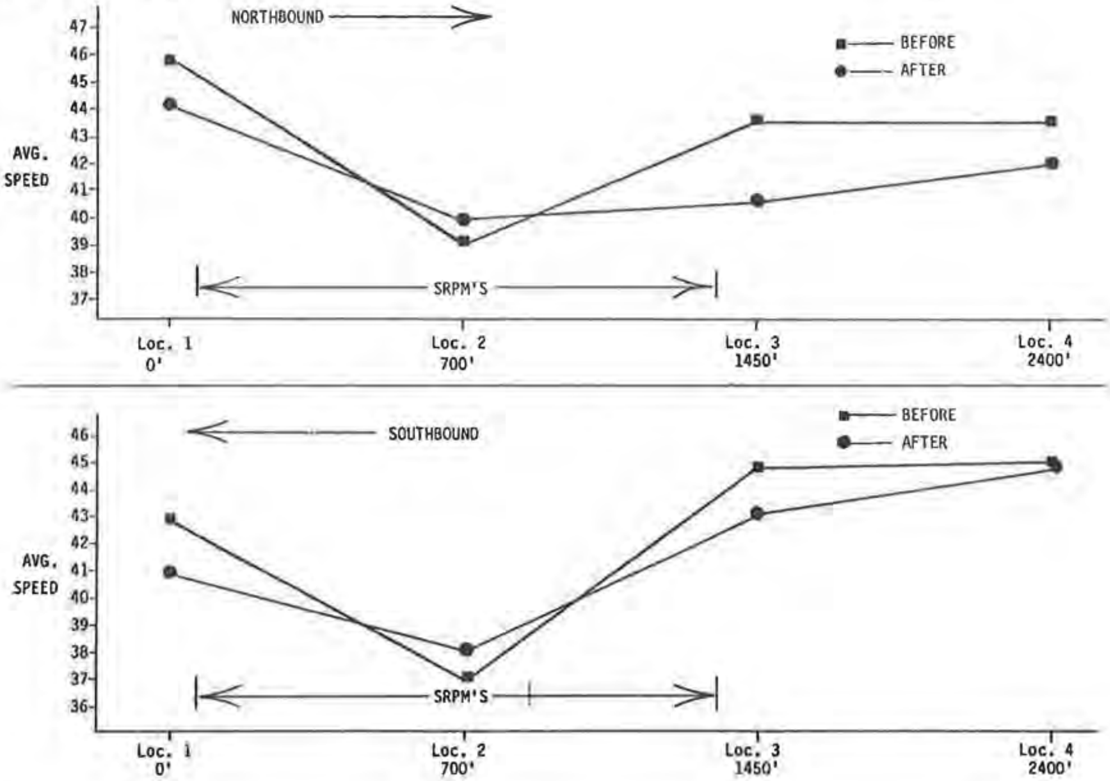
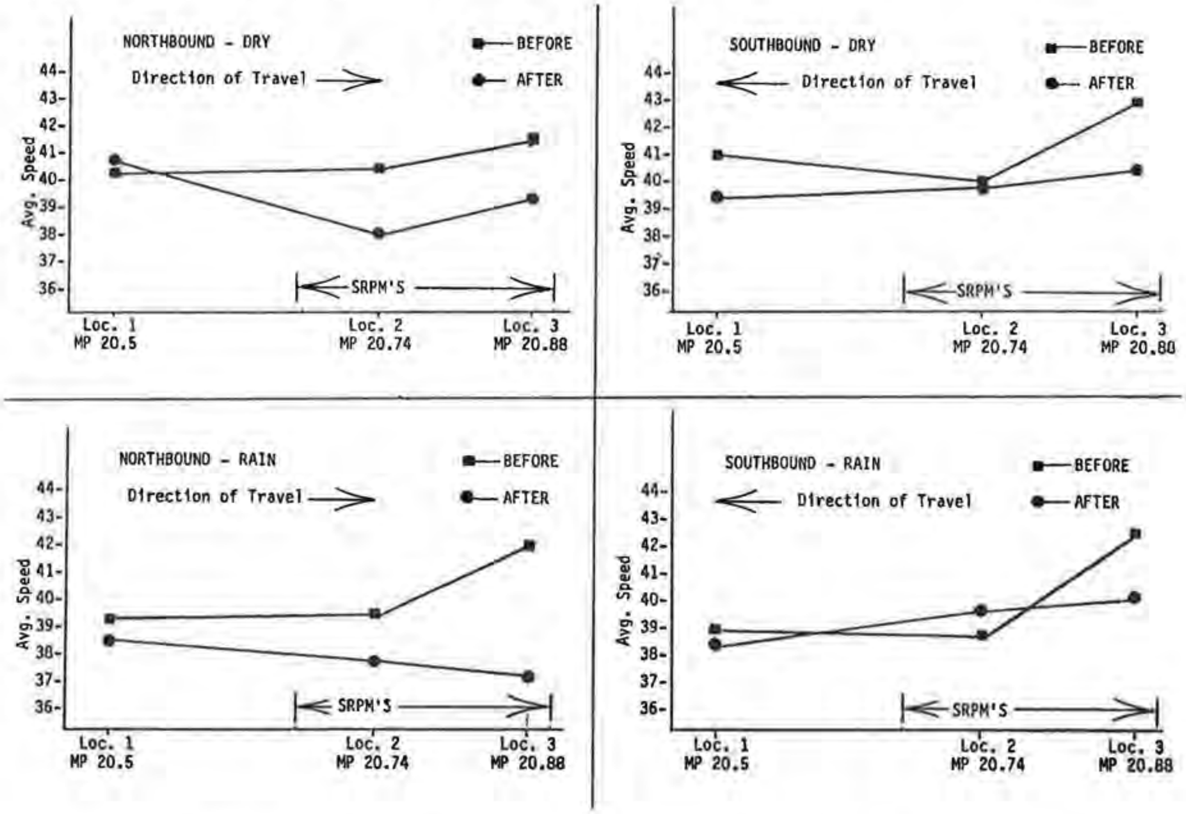


Table 7. Analysis of mean speeds and speed variance at NJ-29.

Location	Direction	Measure	Percentage Before	Percentage After	Percentage Change	Level of Significance (%)
1	Northbound	$\bar{X}$	45.8	44.1	-1.7	>99
		σ	4.2	4.7		
		σ^2	17.6	22.1	+4.5	>95
		n	187	215		
	Southbound	$\bar{X}$	48.8	40.9	-1.9	>99
		σ	5.2	4.6		
		σ^2	27.0	21.2	-5.8	<95
		n	121	147		
2	Northbound	$\bar{X}$	39.0	39.9	+0.9	97
		σ	3.9	4.1		
		σ^2	15.2	16.8	+1.6	<95
		n	194	177		
	Southbound	$\bar{X}$	36.8	38.0	+1.2	98
		σ	4.5	4.6		
		σ^2	20.3	21.2	+0.9	<95
		n	170	139		
3	Northbound	$\bar{X}$	43.4	40.6	-2.8	>99
		σ	4.4	4.5		
		σ^2	19.4	20.3	+0.9	<95
		n	176	249		
	Southbound	$\bar{X}$	44.7	42.9	-1.8	>99
		σ	4.7	5.0		
		σ^2	22.1	25.0	+2.9	
		n	162	210		<95
4	Northbound	$\bar{X}$	43.4	42.0	-1.4	>99
		σ	4.1	4.5		
		σ^2	16.8	20.3	+3.5	<95
		n	171	192		
	Southbound	$\bar{X}$	44.8	44.8	0	
		σ	4.2	4.1		
		σ^2	17.6	16.8	-0.8	<95
		n	137	185		

Figure 4. Effect of SRPMs on vehicle speeds at NJ-35, Belmar.



curred 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, northbound and location 3, southbound) indicate that the markers gave the motorists a cue that the curve was near and prompted them to begin deceleration earlier. 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 phenomena 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 percent level of confidence. As previously stated, this was the only true control site where motorists could neither see nor had passed 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 SRPMs caused a smoothing of the speed profile, the motorists seem to be continuing this effect by gradually increasing their speed.

NJ-35, Belmar

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, and southbound vehicles had just gone through the site. Location 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 a trend toward a smoother speed profile when the markers were present, with the exception of the cars traveling north in the dry condition (Figure 4). As with the previous analysis on NJ-29, this is probably due to the cue the driver receives concerning road geometry that causes an earlier deceleration. In general, speeds were reduced after the SRPMs were installed. Location 2 for southbound cars showed 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 (see Tables 8 and 9).

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 (4) describe erratic maneuvers as noncatastrophic system failures on a scale that includes accidents as catastrophic failures. They further state that "erratic maneuvers are symptomatic of driver uncertainty at the navigational level and may cause serious problems for the traffic stream." A reasonable assumption is that most (or all) accidents are preceded by some erratic maneuver or that such a maneuver, apparently inconsequential in the absence of other vehicles, may be disastrous when performed with other cars around. Hence, the reduction of erratic maneuvers can be an indicator of a safer and more efficient use of the roadway.

The types of erratic maneuvers reduced by the presence of raised markers were painted gore en-

Table 8. Analysis of mean speeds and speed variance at NJ-35, dry conditions.

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

Table 9. Analysis of mean speeds and speed variance at NJ-35, rain condition.

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

croachments, centerline and edgeline encroachments, and lane changes and encroachments. 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. One site experienced a significant decrease in gore encroachments at traffic volumes of 400 vehicles/h/lane but no change in the erratic maneuver rate when more than twice that many vehicles were on the road. Apparently, the vehicles themselves can block the view of the markers and prevent following cars from reacting to the treatment. 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 edgeline encroachments may cause a decrease in fixed-object accidents. There is a concern in some circles that edgeline markings may cause motorists to think there is a lane to the right of the edgeline that perhaps coerces motorists to drive off the road. The results of the study point to the opposite view and show a reduction of vehicles traveling over the edgeline.

Wet weather data were collected at two sites before and after the markers were installed. At one exit, NJ-168, the rate of gore encroachments during rain was not significantly affected by 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. At the second site, a left-side exit with two exit lanes, the percentage of lane changing and encroachments 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.

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 SRPMs, decisions have to be made about where and when the markers should be used. Whether spot treatments of locations that 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 if it can be shown that accidents are reduced by the placement of SRPMs. Research may also be useful in choosing among the use of the markers on Interstate and primary highways or two-lane rural roads. Although the former would most likely have higher vehicle miles of travel per lane mile of marked roadway, the dark, winding nature of many rural roads, and the presence of fixed obstacles near to the roadway may point to their being considered a higher priority.

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STOP Sign Versus YIELD Sign

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This paper investigates the relative effectiveness of STOP and YIELD signs at low-volume intersections (less than 500 vehicles/day on minor roadway) in rural and urban environments. Traditional rationales for installing STOP signs, such as inadequate sight distance and high volumes on major roadways, are examined. It is shown that the current use of STOP signs is unrelated to sight distance availability and that STOP signs do not categorically reduce accidents at low-volume intersections. Further, no relation is demonstrated between accidents and major roadway volumes up to 6000 vehicles/day. STOP signs are shown to increase road user costs by more than 7 percent over YIELD signs.

The STOP sign is by far the most prevalent traffic control at intersections. Its message is simple and clear, and the expected response of motorists is a complete cessation of motion (1). The distinct color and shape of the STOP sign result in quick recognition by motorists. Despite its clear meaning, Stockton and others (2), in a study sponsored by the Federal Highway Administration (FHWA), reported that less than 20 percent of the motorists voluntarily complied by completely stopping at STOP signs. (Motorists who had to stop at a STOP sign because of traffic conditions were excluded from the computation.) This compliance rate of 20 percent represents an overall average of three states: Florida, Texas, and New York. A total of 140 intersections in urban and rural environments were sampled. At least one roadway had average daily traffic (ADT) of 500 or fewer vehicles; major road volume ranged up to 36 000 vehicles/day and did not meet the Manual of Uniform Traffic Control Devices (MUTCD) (3) volume warrants for traffic signals.

Dyar (4) also investigated driver's observance of STOP signs at rural and urban intersections in South Carolina. He reported a voluntary compliance rate of 11 percent. Stockton, however, noted that the difference in compliance rates among the three states studied was significant. Such low compliance rates indicate that STOP signs are being used indiscriminately; hence, the sign's purpose of providing for orderly and predictable movement of traffic is defeated.

MUTCD REQUIREMENTS

MUTCD states that (3), to be effective, a traffic control device should meet five basic requirements:

1. Fulfill a need;
2. Command attention;
3. Convey a clear, simple meaning;