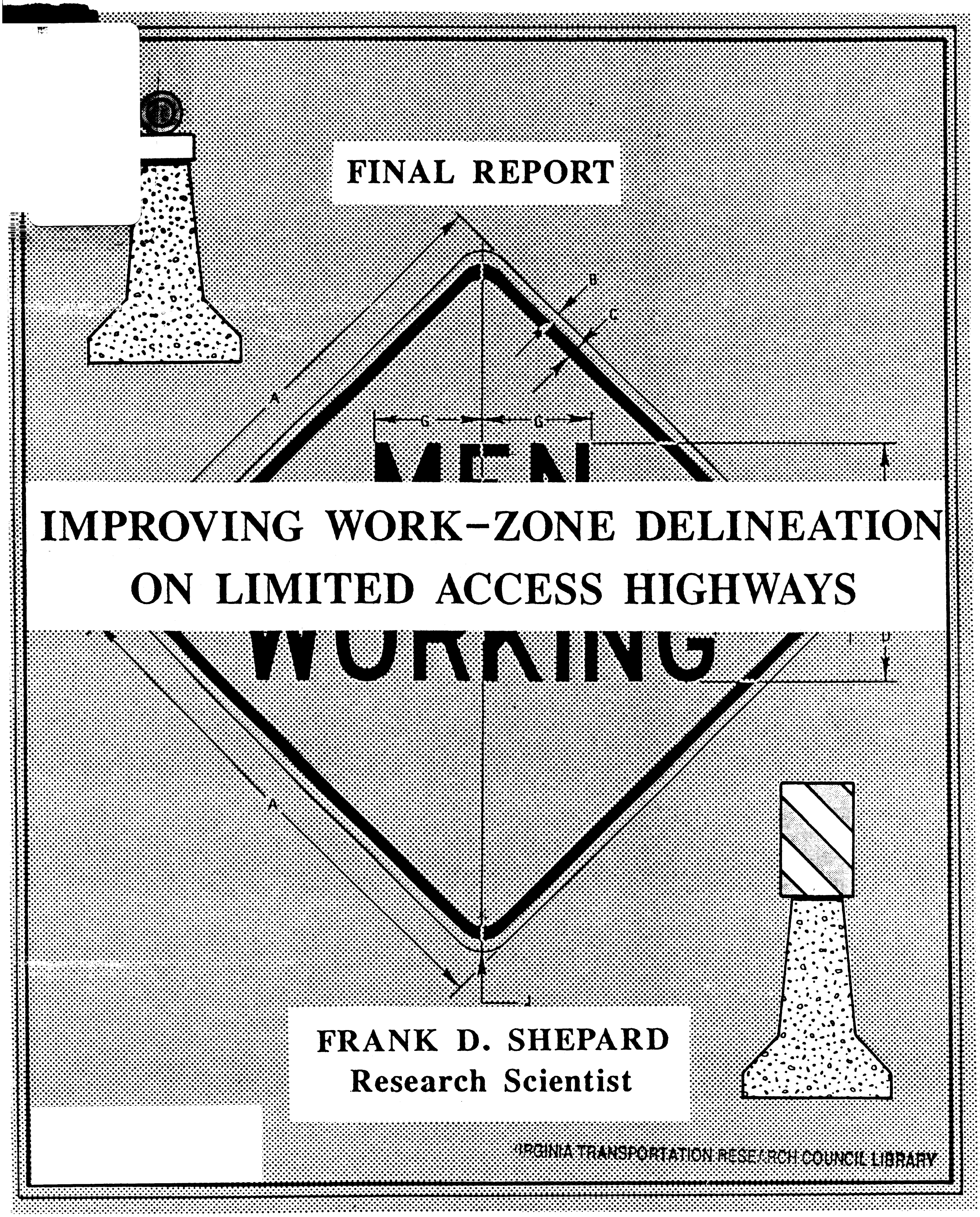
FINAL REPORT

IMPROVING WORK-ZONE DELINEATION ON LIMITED ACCESS HIGHWAYS



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16. Abstract

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The results of this investigation have led to the recommendation that (1) steady-burn lights on temporary concrete barricades should be replaced with reflectorized panels fabricated with high intensity sheeting, and (2) closely spaced, raised pavement markers should be used as a supplement to existing pavement striping in areas where the roadway alignment changes.

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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In Cooperation with the U.S. Department of Transportation
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ABSTRACT

The purpose of this study was to investigate vehicle guidance through work zones by evaluating the effectiveness of two primary components of traffic control relative to delineation. First, a comparison of the steady-burn lights presently used on top of the temporary concrete barriers was made with experimental reflectorized panels. Second, the addition of closely spaced raised pavement markers as a supplement to the existing pavement markings was evaluated. The study was limited to work zones on interstates and four-lane highways.

The results of this investigation have led to the recommendation that (1) steady-burn lights on temporary concrete barricades should be replaced with reflectorized panels fabricated with high intensity sheeting, and (2) closely spaced, raised pavement markers should be used as a supplement to existing pavement striping in areas where the roadway alignment changes.

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INTRODUCTION

With traffic volumes increasing and many roads already operating at or near capacity, the upsurge in highway construction coupled with the rehabilitation of existing facilities will result in the motoring public having a greater exposure to work-zone activities.

The seriousness of the problem of safety in work zones is reflected in FHWA statistics that show that work-zone fatalities have risen from 489 in 1982 to 678 in 1985. Virginia statistics show that in 1985 29 people died and 167 were seriously injured in work-zone accidents. Work-zone safety is therefore a high priority item, and it is important that ways of protecting the motoring public and the work force be found.

One way of increasing work-zone safety involves providing clear and positive guidance for motorists approaching and traversing the area. Whenever a work zone is present, motorists are required to travel a section of highway that may be different from what they expect. In most cases, drivers are required to deviate from their expected travel path because of narrow lanes, closed lanes, and detours.

The magnitude of the problem is demonstrated by the following list, which encompasses the sources of confusion prevalent within work zones.

- Roadway geometry and alignment are different from the original and expected layout.
- There are conflicting travel cues, including different pavement colors and textures; pavement joints are not parallel to traffic flow or are not between lanes of travel.
- Old pavement markings often have not been eradicated, and eradicated markings create different roadway color and texture.
- There is a lack of visibility because of weather, lighting, dirt, and/or worn pavement markings.
- There is a lack of uniform application of markings within similar work zones.
- Drivers' views of markings are obstructed by a high volume of traffic or by trucks.
- Opposing headlight glare is greater than normal.

All of these sources of confusion impose an added burden on drivers at the same time that they are forced to perform a maneuver that may be unfamiliar and unexpected.

Therefore, it is important that every effort be made to reliably indicate the direction of road alignment and the severity of any change in direction. As the Manual on Uniform Traffic Control Devices (MUTCD) states: "the intended vehicle path should be clearly defined during day, night, and twilight periods under both wet and dry pavement conditions."

In work zones, the Virginia Department of Transportation provides an array of traffic control devices including signs, pavement markings, delineators, steady-burn lights, and barriers, all of which define travel lanes. Two components of this traffic control system that influence motorist guidance are steady-burn lights placed on top of the concrete barriers and pavement markings placed on the roadway. Because of the importance of using optimal delineation techniques in work zones, the effectiveness of these two traffic control systems will be investigated.

Steady-Burn Lights

Steady-burn lights are used in Virginia to help delineate the vehicle path through and around obstructions in a construction or maintenance area. They are used in conjunction with precast concrete traffic barriers and are placed on top of the barriers at 80-ft centers on the barrier taper (between chevrons) and tangent sections. Although the steady-burn lights on top of the concrete barrier are quite visible, there are several reasons to question their use.

- o Lights are dependent on batteries, and thus they require maintenance. When lights burn out, the 160-ft spacing leaves partial and often confusing guidance.
- o Many states use steady-burn lights on a limited basis. For example, New Jersey found that the use of 6 in x 12 in reflectorized panels in lieu of steady-burn lights caused no decrease in the proportion of vehicles using the lane adjacent to the temporary construction barrier and caused no change in the mean speed and speed variance. The New Jersey DOT has been using the reflectorized panels on tangent sections of the temporary concrete barrier for 5 years and has reported no problems. Lights are still used in the taper area.
- o Steady-burn lights are relatively expensive; they cost from $0.70 to $1.40 per light per day.
- o Recent research by the Research Council investigated the use of reflectorized panels for use as concrete barricade delineators (as a substitute for lights). It was found that the devices were feasible in terms of application and cost.

Because of these concerns, the possibility of replacing the steady-burn lights with reflectorized panels was investigated.

Pavement Markings

Pavement markings serve an important function since they help provide a smooth, safe transition from one lane to another, onto a bypass or detour, or in reducing the width of the traveled way. Pavement striping is primarily used to clearly define the intended vehicle path during day, night, and twilight periods under both wet and dry pavement conditions.

One technique that can be used to enhance work-zone delineation involves the use of raised pavement markers as a supplement to the pavement striping. Raised pavement markers are very bright and protrude above the road surface to provide improved visibility, especially during hazardous wet pavement conditions at night. The effectiveness of raised pavement markers was summarized in a previous study. It was the consensus of eleven highway agencies that the use of raised pavement markers in high-hazard locations did enhance the delineation and improve the overall safety of the locations (1). This and many other studies (2,3,4) have been conducted concerning the advantages of using raised markers for roadway delineation; however, it is felt that there is still room for improvement in techniques for work-zone delineation. Virginia recently conducted preliminary studies using different raised marker devices and different spacing as a supplement to existing edge line markings. These techniques provided positive guidance in the transition areas.

PURPOSE AND SCOPE

The purpose of this study was to investigate vehicle guidance through work zones by evaluating the effectiveness of two primary components of traffic control relative to delineation. First, a comparison of the steady-burn lights presently used on top of the temporary concrete barriers was made with experimental reflectorized panels. Only tangent sections of the work area were considered (no transitions).

Secondly, the addition of closely spaced raised pavement markers as a supplement to the existing pavement markings was evaluated. Observations were limited to areas where the roadway alignment deviated from the original, i.e., lane/road transitions and detours.

The study was limited to work zones on interstates and four-lane highways.

STEADY-BURN LIGHTS

Steady-burn lights and reflectorized panels were placed on top of temporary concrete barriers along the tangent sections only. These devices (see Figure 1) were compared at two sites. Site 1 (see Figure 2) was a four-lane divided highway that had two lanes closed; therefore, the two southbound lanes carried two-way traffic separated by temporary concrete barriers on which the lights and panels were placed. The barrier was placed on the left side of traffic, and 37 delineators were spaced at 72-ft intervals.

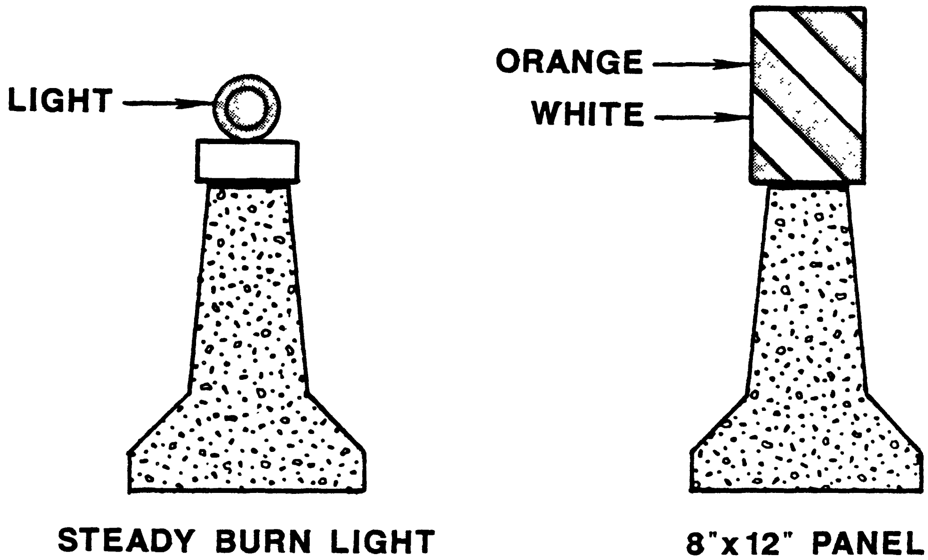

Figure 1. Concrete barrier delineators.

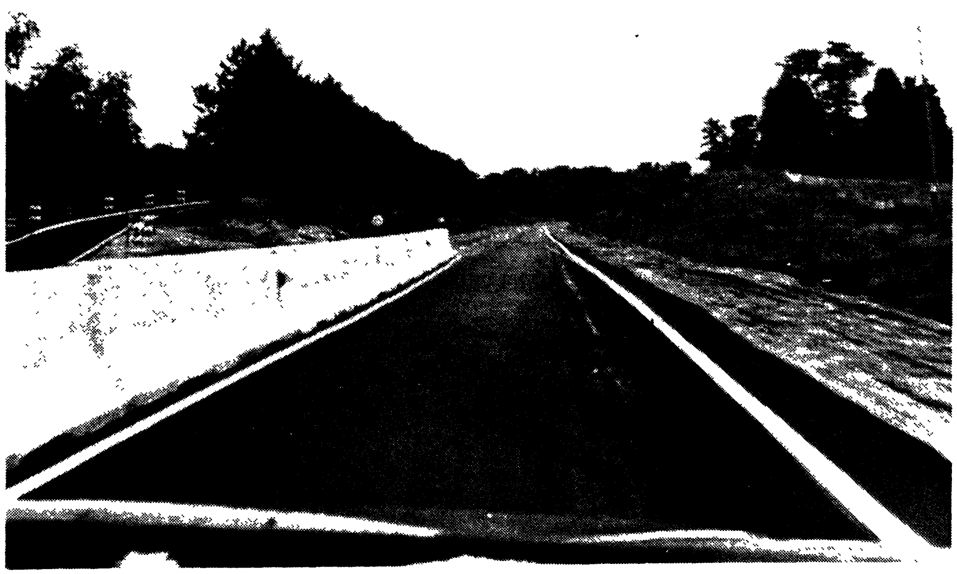

Figure 2. Site 1, Rt. 29, Leon, Virginia.

Site 2 (see Figure 3) was an interstate highway that had temporary concrete barriers placed on the right shoulder. There were 17 delineators spaced 48 ft apart on the top of the temporary concrete barricade.

Figure 3. Site 2, Interstate 85, Petersburg, Virginia.

Procedure

As a measure of the effectiveness of the steady-burn lights and reflectorized panels, traffic flow data were collected using a system of traffic counters with rubber tubes.

1. Vehicle Speed: Vehicle speeds were recorded using two tubes as a speed trap.

2. Vehicle Placement: The placement of vehicles relative to the lane line next to the concrete barrier was recorded using different length tubes.

All data were collected on weekdays between the hours of darkness and 5:00 a.m.

Videos were taken of the test sections for the purpose of documentation.

Results

Vehicle Placement

Vehicle placement was determined at site 1 by observing the number of vehicles at 0-1.5, 1.5-3.0, 3.0-4.5, and 4.5-6.0 ft intervals from the edgeline for each delineation treatment. Figures 4 and 5 show the percentage of vehicles within each interval from 8:00 p.m. to 1:00 a.m. and 1:00 a.m. to 5:00 a.m., respectively. Data were collected two weekdays for each time period and each set of delineators. The results indicate no difference in vehicle placement using the steady-burn lights or the reflectorized panels. It is interesting to note that there was a difference in placement between the two time intervals, probably because of heavy truck traffic during the early morning hours.

Vehicle placement from 9:00 p.m. to 1:00 a.m. and 1:00 a.m. to 5:00 p.m., for the steady-burn lights and reflectorized panels at site 2 is shown in Figures 6 and 7, respectively. Two weekdays of data were collected for each period and delineation treatment. There were differences in vehicle placement for both periods. The 2- to 4-foot interval and the 9 p.m. to 1:00 a.m. time period had 5.4 percent more vehicles for the reflectorized panels, whereas, the 6- to 8-foot interval had 5.8 percent fewer vehicles. Also for the 1:00 a.m. to 5:00 a.m. time period, 6 percent more vehicles were found for the reflectorized panels with a placement interval of 4 to 6 ft, and 6 percent fewer vehicles were shown for the 6- to 8-foot interval. This indicates that fewer vehicles were straying from the lane adjacent to the concrete barricades using reflectorized panels as compared with the steady-burn lights.

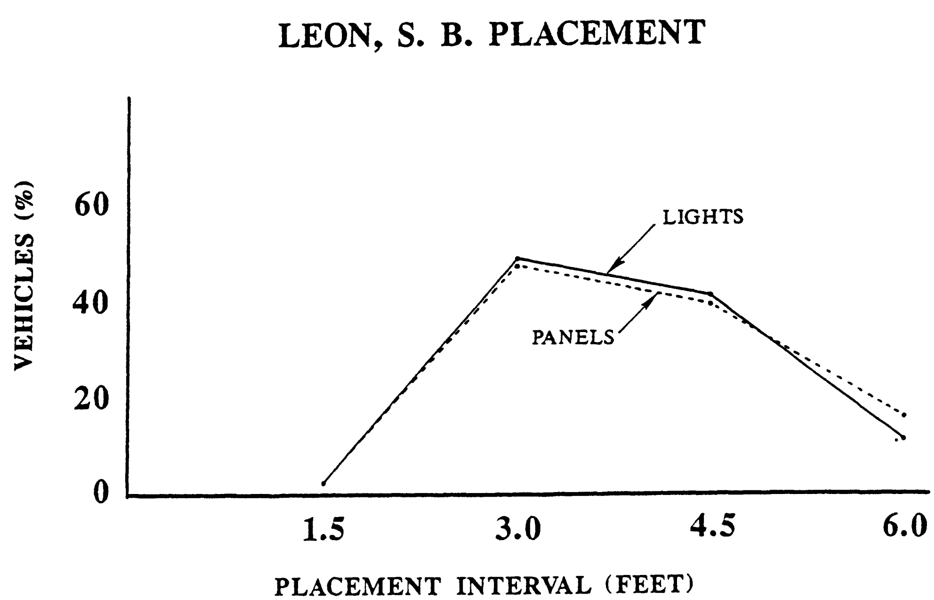

Figure 4. Percent vehicle placement from 8:00 p.m. to 1:00 a.m. (Site 1 - Leon)

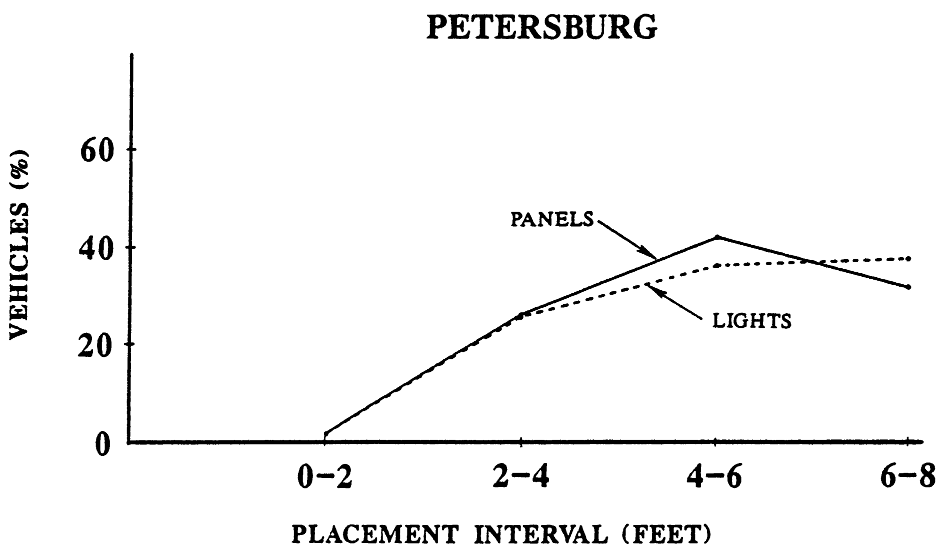

Figure 7. Percent vehicle placement from 1:00 a.m. to 5:00 a.m. (Site 2 - Petersburg)

Vehicle Speeds

Table 1 shows the average vehicle speeds observed at sites 1 and 2 from 8:00 p.m. to 1:00 a.m. Two weekdays of data were collected for the steady-burn lights and reflectorized panels.

Table 1

Vehicle Speeds for Concrete Barrier Delineation

	Lights	Panels
Site 1	53.4	53.0
Site 2	55.7	56.3

The results show no significant difference in speeds between the two delineation treatments.

Videos of Test Sites

Videos were taken at the following test sites:

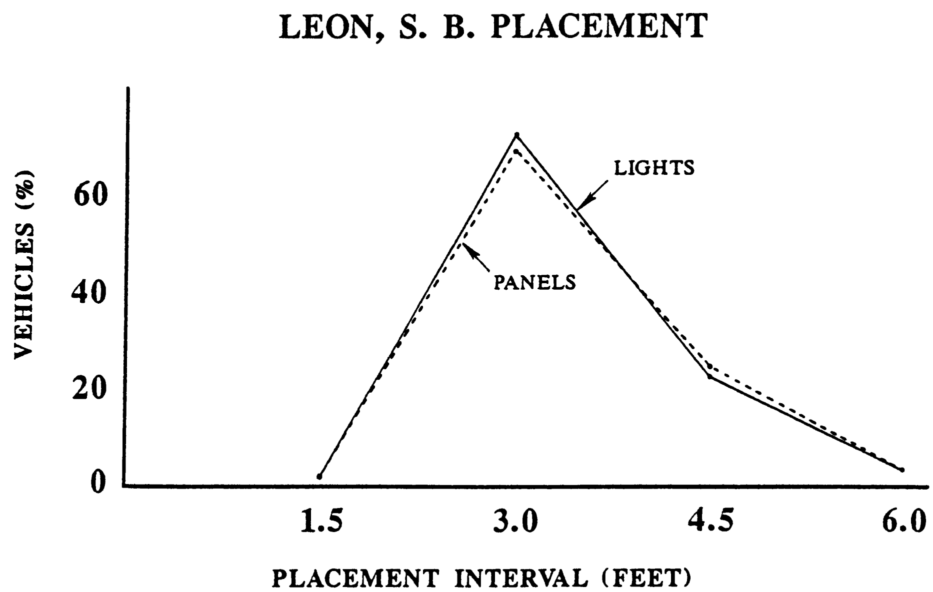

Figure 5. Percent vehicle placement from 1:00 a.m. to 5:00 a.m. (Site 1 - Leon)

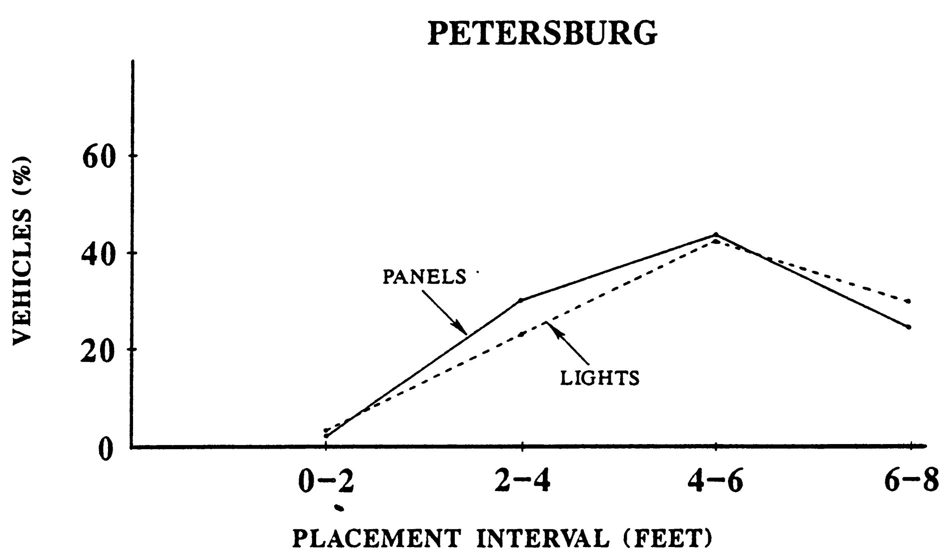

Figure 6. Percent vehicle placement from 9:00 p.m. to 1:00 a.m. (Site 2 - Petersburg)

Light vs. Panels

- o Site 1 (Leon S.B.)
  - Daytime
  - Night/dry
  - Night/wet
- o Site 2 (Petersburg)
  - Daytime
  - Night/dry

RAISED PAVEMENT MARKERS

The use of raised pavement markers as a supplement to the existing work zone pavement markings was investigated for three sites. The raised markers were placed within the transition areas or where the alignment deviated from the original. Temporary markers were plastic with curve-corner face reflectors and were placed using a butyl pad.

Site 1 (see Figure 8) was a detour for a four-lane divided highway; the northbound lanes were closed. The S-shaped detour had preformed tape along the right edgeline and a painted stripe along the left edgeline. The schematic in Figure 9 shows the location and spacing of raised pavement markers and the data collection points.

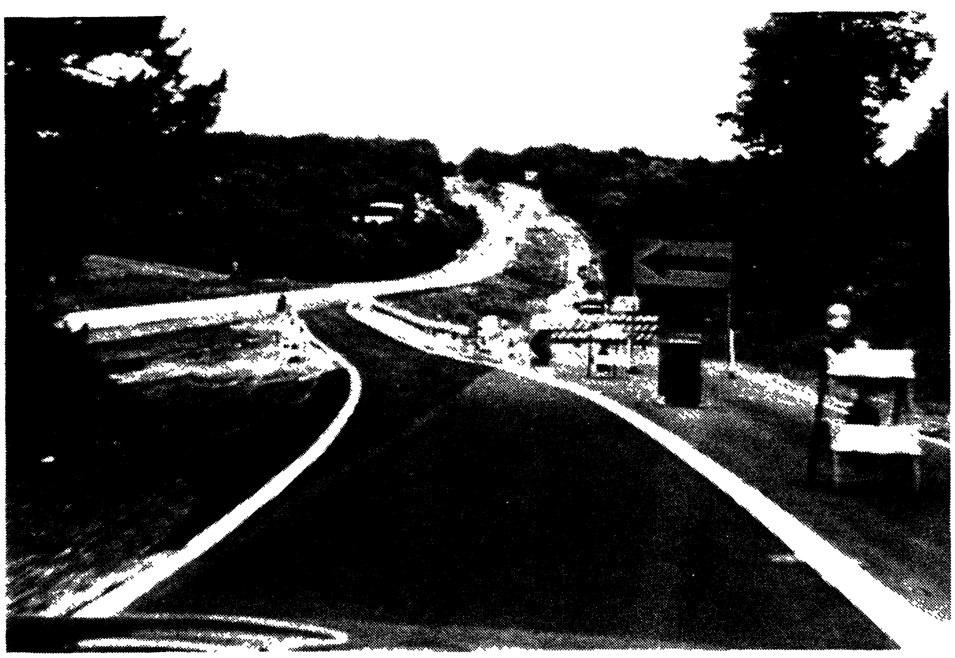

Figure 8. Site 1, Rt. 29, Leon, Northbound.

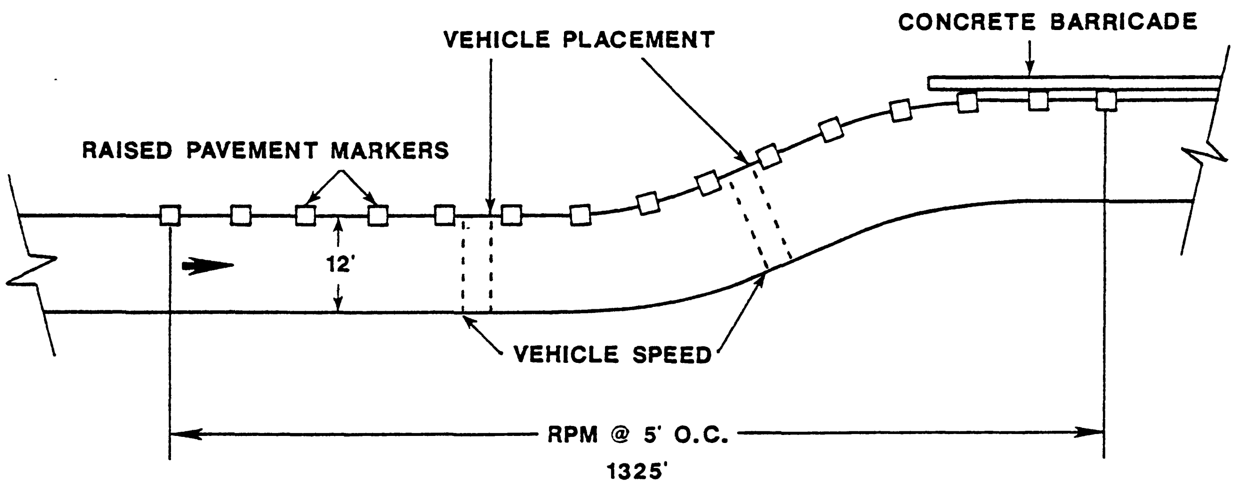

Figure 9. Schematic of Site 1, Leon.

Site 2 (see Figure 10) was a four-lane highway with the right lane closed. Raised pavement markers were added to the existing markings along both the right transition and left centerline. The schematic in Figure 11 shows the location and spacing of the markers.

Site 3 (see Figure 12) was an interstate, left lane closure, with raised markers supplementing the existing left edgeline transition. The markers were placed directly on the new preformed tape. The schematic in Figure 13 shows the marker placement and data collection points.

Figure 10. Site 2, Route 1, Fredericksburg.

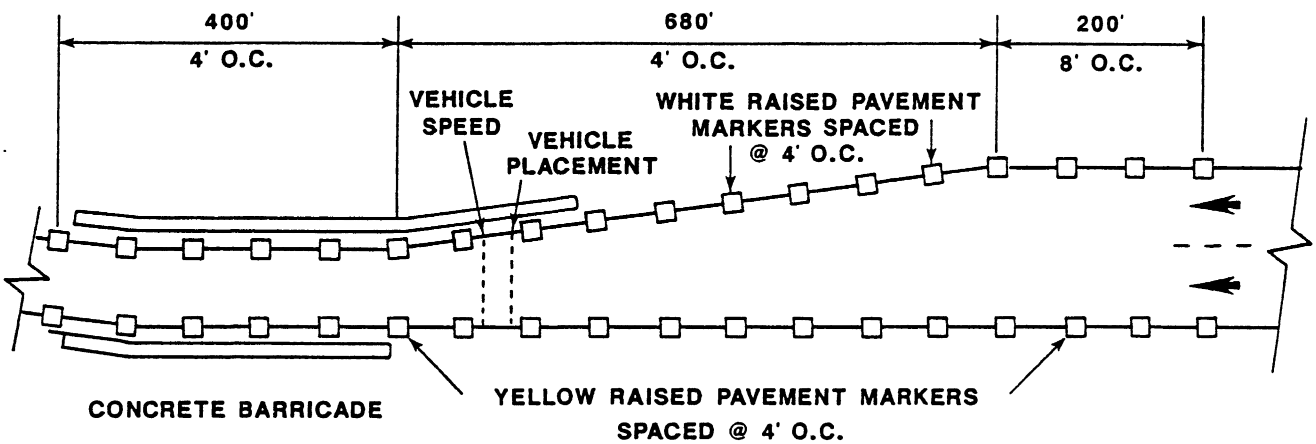

Figure 11. Schematic of Site 2, Fredericksburg.

Figure 12. Site 3, Interstate 81, Salem.

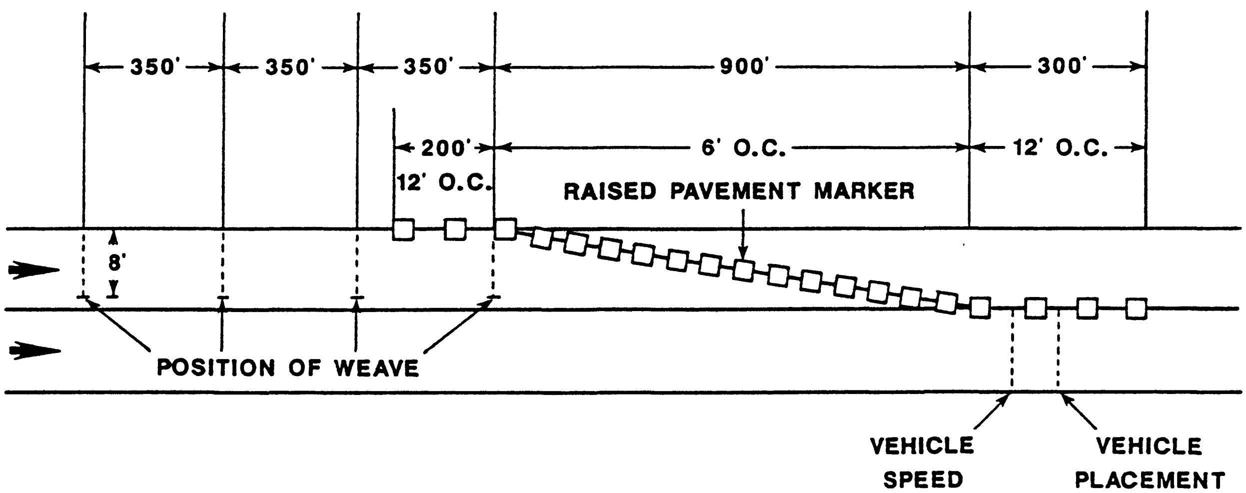

Figure 13. Schematic of Site 3, Salem.

Procedure

As a measure of the effectiveness of the pavement striping and striping supplemented with raised pavement markers, traffic-flow data were collected using a system of traffic counters with rubber tubes.

- Vehicle Speed: Vehicle speeds were recorded using two tubes as a speed trap.
- Vehicle Placement: The placement of vehicles relative to the lane line next to the concrete barrier was recorded using different length tubes.
- Position of Weave: The position of weave within the transition area was recorded by dividing the area into zones and determining the magnitude of weaving within each zone.

Because of the importance of delineation during night/wet conditions, it was hoped that each variable could be tested under wet conditions; however, a lack of rain limited data collection to dry conditions.

All data were collected on weekdays between the hours of darkness and 5:00 a.m.

Videos were taken of the test sections for the purpose of documenting the pavement markings observed.

Results

Vehicle Placement

Vehicle placement was measured for sites 2 and 3. Figures 14 and 15 show vehicle placement for site 2 from 9:00 p.m. to 1:00 a.m. and from 1:00 a.m. to 5:00 a.m. For both time intervals, there were more vehicles in the 2- to 4-ft interval for the raised pavement markers as compared with no raised markers. Fewer vehicles were in the 6- to 8-ft interval from 9:00 p.m. to 1:00 a.m. and in the 4- to 6-ft interval from 1:00 a.m. to 5:00 a.m. for the raised markers. With a 12-ft pavement width at the point at which the placement was taken, this means that vehicles were staying closer to the center of the lane.

Placement for site 3 is shown in Figures 16 and 17. Very little difference in vehicle placement was found for each time period.

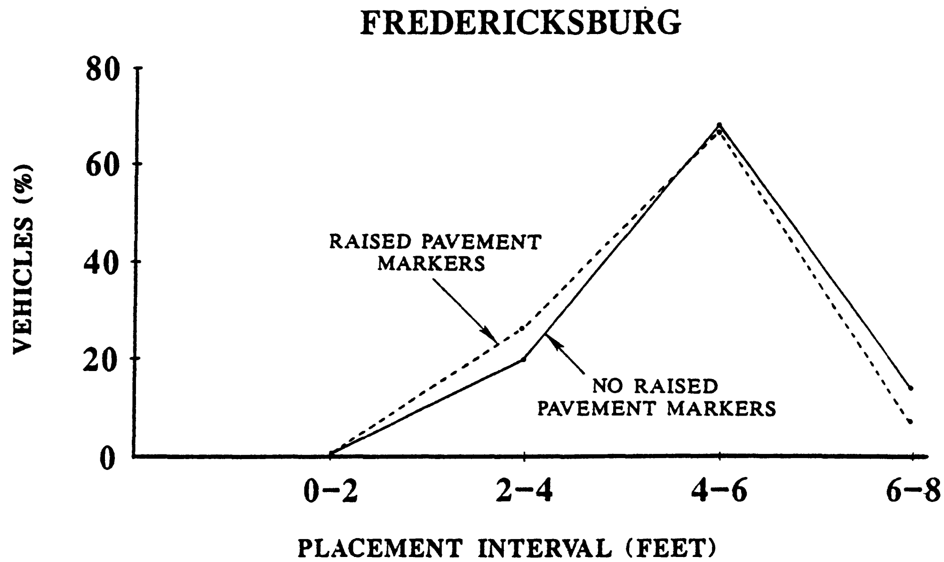

Figure 14. Percent vehicle placement from 9:00 p.m. to 1:00 a.m. (Site 2 - Fredericksburg)

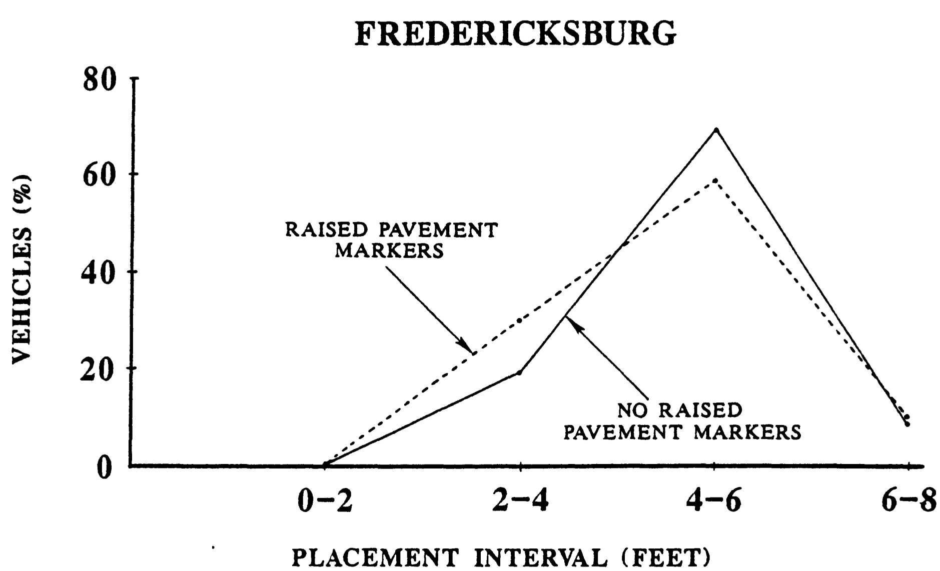

Figure 15. Percent vehicle placement from 1:00 a.m. to 5:00 a.m. (Site 2 - Fredericksburg)

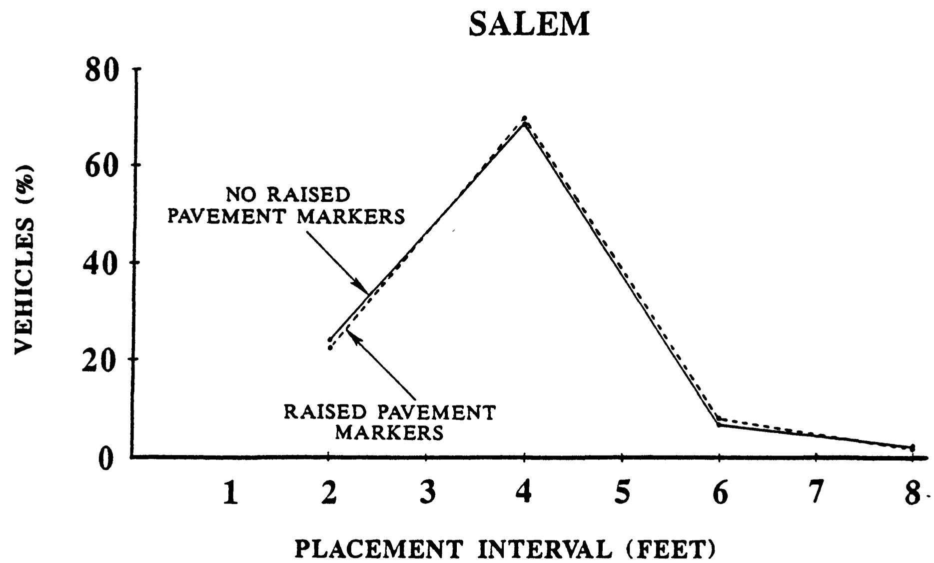

Figure 16. Percent vehicle placement from 9:00 p.m. to 1:00 a.m. (Site 3 - Salem)

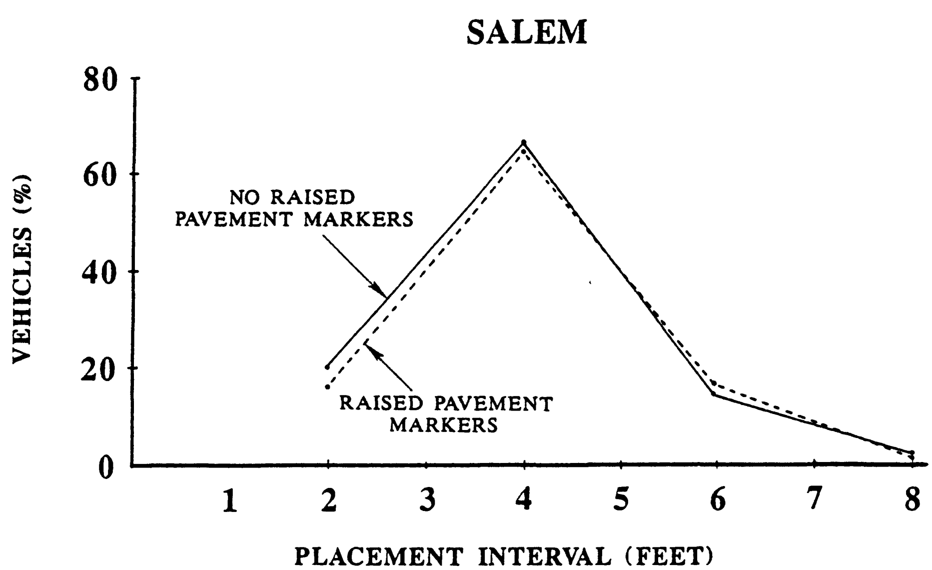

Figure 17. Percent vehicle placement from 1:00 a.m. to 5:00 p.m. (Site 3 - Salem)

Discussion of Results

It is noted that raised pavement markers are most effective during night-wet conditions, since the water significantly reduces the retroreflection capabilities of the pavement striping, leaving the raised pavement marker, which protrudes above the water, as a primary source of reflected light. The unavailability of appropriate wet conditions during testing prevented data from being obtained during the time when raised pavement markers are the most effective, i.e., night-wet conditions. Figure 18 shows an example of the raised pavement markers used at site 1 (Leon, N.B.) during wet conditions. The positive guidance capabilities are obvious. Note the low visibility of the painted line. Existing pavement striping at site 2 was judged to be average with some parts below average, primarily because of the poor pavement conditions (cracks, scaling, irregular surface resulting from milling, dirt accumulation, etc.). Therefore, it was felt that the addition of the raised markers at site 2 would increase delineation by creating a brighter path for motorists to follow. This observation seems to be supported by the placement data, which show that a higher percentage of vehicles traveled in the center of the lane, with less encroachment on the centerline.

Figure 18. Raised pavement markers and night/wet conditions at Leon.

Site 3 revealed little difference in vehicle placement with and without the raised pavement markers. This site, however, had new preformed tape for the transition on which the raised markers were placed. This material remained very bright during the test period and provided good guidance. Because of the brightness of the tape, the raised pavement markers did not provide the contrast needed for increased delineation. Therefore, it is not surprising that little difference in vehicle placement was found between the use of raised pavement markers and their absence. Under wet pavement conditions, especially heavy rain, the brightness of the pavement striping would be greatly diminished, leaving the raised markers as the primary source of guidance.

Vehicle Speeds

Table 2 gives the average vehicle speeds for the three sites. Site 1 had two speed observation points. Speeds were observed for all sites between the hours of 9:00 p.m. and 1:00 a.m. The same weekday was used for comparing each delineation treatment. Posted advisory speed limits were 25, 55, and 45 mph, respectively, for Leon, Salem, and Fredericksburg.

Table 2

Average Speeds

	Vehicle Speeds (MPH) No RPM	RPM
Site 1a	41.5	43.5
1b	43.6	50.0
(Leon)		
Site 2 (Salem)	56.3	55.7
Site 3 (Fredericksburg)	43.6	45.6

These results show an increase in average speed for sites 1a, 1b, and 3. There was little difference (0.6 mph) observed at site 2. The raised pavement markers provided more contrast or brightness than the painted lines on which they were placed at sites 1 and 3, and thus accounted for the speed differential. Also, delineation at the site 1 detour was felt to be more critical because of the narrow lanes, S-shaped curves, and downhill topography. As noted earlier, the relative brightness of the tape edgeline at site 2 caused the raised markers to be less effective, which resulted in the small difference in speeds at that site.

Position of Weave

The position of weave was observed for site 3 by recording the number of vehicles in the left lane at the taper and at distances of 350 ft, 700 ft, and 1,050 ft from the beginning of the taper. Table 3 gives the percentage of vehicles in the left lane from 9:00 p.m. to 1:00 a.m. and 1:00 a.m. to 5:00 a.m. Two time intervals were used because of the different characteristics of early and late night traffic.

Table 3

Position of Weave for RPM vs. No RPM

Time	Position							
	1,050'		700'		350'		at taper	
	No RPM	RPM	No RPM	RPM	No RPM	RPM	No RPM	RPM
9:00 p.m. to 1:00 a.m.	3.6%	3.6%	2.7%	2.7%	1.7%	1.6%	0.5%	0.4%
1:00 a.m. to 5:00 p.m.	1.5%	0.7%	1.0%	0.4%	0.5%	0.5%	0.2%	0.4%

These data indicate that the addition of the raised pavement markers did not change the position of weave of vehicles approaching the left lane closure.

Videos of Test Sections

The following videos were taken of the test sections:

Pavement Striping vs. Pavement Striping and Raised Pavement Markers

- Site 1, Leon, N.B.
  - Daytime
  - Night/dry
  - Night/wet
- Site 2, Fredericksburg
  - Daytime
  - Night/wet
- Site 3, Salem
  - Daytime
  - Night/dry

CONCLUSIONS

Steady-Burn Lights vs. Reflectorized Panels

Analysis of vehicle placement data at two sites show no difference at one site, whereas the other revealed less straying from the lane for the reflectorized panels. Speed data comparisons showed no differences in speeds at the two sites; therefore, it is concluded that the reflectorized panels were at least equal to or superior to the steady-burn lights.

Use of Raised Pavement Markers to Supplement Existing Striping

The addition of raised pavement markers influenced vehicle placement at site 2 by causing fewer centerline encroachments, although little change was noted for site 3.

Vehicle speeds increased at both observation points at site 1 and at site 3; whereas no change was seen at site 2. The increase in speed indicates that the drivers were more comfortable and confident of the roadway alignment and the path to follow.

For the night-dry conditions under which the raised markers were tested, these were positive results that favored the use of raised pavement markers for supplementing existing striping.

The temporary raised markers were applied to the surface of preformed tape at one site and over new paint at another, using butyl pads in both cases with good retention and durability. However, the site on which the markers were placed over paint, which had been applied to deteriorated pavements, old paint lines, and milled pavement surfaces, had definite problems with marker retention. The primary problem was the failure of the paint to adhere to the pavement or old painted surface, thereby causing the marker, along with the underlying striping, to become detached, especially when vehicle tires hit the markers.

Although it was not within the scope of the project to test methods of adhesion, marker retention and durability will have to be considered if raised markers are to be used.

RECOMMENDATIONS

Steady-Burn Lights vs. Reflectorized Panels

It is recommended that consideration be given to replacing the steady-burn lights on temporary concrete barricades with reflectorized panels. The panels would be at least the size of the ones used in this study, and they should be fabricated with high intensity sheeting. The panels should be positioned at the same intervals as the steady-burn lights; however, they should be placed along the tangent sections only. Steady-burn lights should continue to be placed in the taper areas. Stripes on the panel should slope down toward the pavement. A recent study (5) showed that the cost of steady-burn lights was 10 to 20 times the cost of reflectorized panels (8" x 12"); therefore, the Department would realize a substantial savings from the use of the panels.

Use of Raised Pavement Markers to Supplement Existing Striping

The use of raised pavement markers as a supplement to existing striping showed signs of helping motorists negotiate work-zone areas where there are changes in roadway alignment. These results were for dry conditions; wet conditions should lead to even greater advantages.

The use of closely spaced, raised pavement markers is a definite advantage to motorists because of the positive guidance provided as they approach and drive through work zones that present a variety of roadway alignment changes, which are often confusing.

Because of the importance of providing positive motorist guidance and a safe driving environment within work zones, it is recommended that the Department use raised pavement markers as a supplement to existing pavement striping in areas where the roadway alignment changes (transitions, detours, etc.). There are still many questions to be answered relative to location, spacing, retention, durability, and type of raised marker. Until these questions can be answered, it is recommended that the markers be spaced on 4- to 5-ft centers in areas where there are curves or transitions and 8- to 10-ft centers for tangent sections. The method of application to the roadway should allow the marker to be placed and/or replaced in a minimum amount of time and with a minimum amount of disruption to the traffic flow. Adhesives that can be attached to the marker that in turn can be hand applied are preferable. The marker should be placed on the surface of the edgeline marking if this marking is judged to be securely adhered to the pavement surface. For questionable striping, the marker can be placed adjacent to the line, making sure that the pavement is free of dirt, grime, etc.

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