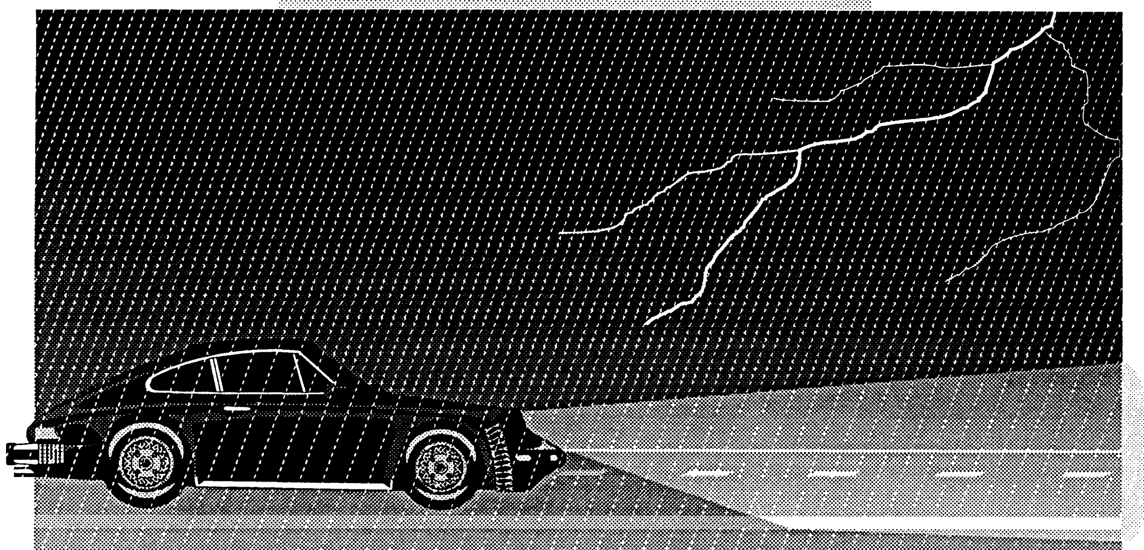
FINAL REPORT

EVALUATION OF PAVEMENT MARKINGS FOR IMPROVED VISIBILITY DURING WET NIGHT CONDITIONS



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VIRGINIA TRANSPORTATION RESEARCH COUNCIL

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16. Abstract

This study evaluated the night visibility of waffle tape and paint with large beads, particularly during wet night conditions. Data were collected at two sites along a primary arterial.

The evaluation included an examination of (1) the application of the markings, (2) the visibility of the markings using retroreflectometer measurements and subjective assessments, and (3) the cost-effectiveness of the markings.

The study revealed: (1) compared to paint with standard beads, the waffle tape and paint with large beads were slightly more retroreflective during light rain at night and recovered quicker after flooding out, (2) the marginal improvement in visibility during periods of light rain do not offset the operational problems of applying paint with large beads, and (3) the benefits of waffle tape during light rain do not appear to justify its use solely for wet night visibility. Because of the above findings, snowplowable raised pavement markers, which are very visible in wet night conditions, appear to be more cost-effective.

The study recommends that (1) VDOT continue to use and maintain snowplowable raised pavement markers for visibility during wet night conditions, (2) VDOT continue to monitor FHWA's study on all weather pavement markings, and (3) the Suffolk District consider testing nonsnowplowable raised pavement markers to assess their use as a low-cost alternative to improve visibility during wet night conditions where snowplowing occurs infrequently.

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Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

May 1996
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ABSTRACT

This study evaluated the night visibility of waffle tape and paint with large beads, particularly during wet night conditions. Data were collected at two sites along a primary arterial.

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INTRODUCTION AND PROBLEM STATEMENT

Pavement markings convey much of the visual information needed by a driver to navigate safely in a variety of weather and light conditions. Visibility during wet night conditions is particularly important to the Traffic Engineering and Materials Divisions of the Virginia Department of Transportation (VDOT) because the visibility of many pavement markings is worse on wet nights. When headlight beams shine on dry pavement markings at night, the glass beads retroreflect, that is, the light is reflected back at the driver. When conventional markings (specifically the standard size glass beads in the paint) are covered with a film of water, the light is reflected in all directions. Only a small portion of light is reflected back to the light source, greatly reducing the visibility (or retroreflectivity) of the markings. Of course, pavement markings with better wet night retroreflectivity also have better dry night retroreflectivity as well.

Several new pavement marking products are designed to enhance wet night retroreflectivity. These products fall into two groups: large glass beads, and textured markings.

The large glass beads are about three times the size of standard beads (Figure 1). In a water film that would cover the standard beads under wet night conditions, part of the large beads may still be above water and provide retroreflectivity.

Some textured markings have a pattern of raised walls or vertical surfaces higher than the traditional marking surface. The raised wall may remain above the water film, providing retroreflectivity under wet night conditions. The textured surface may also provide an audible rumble under the vehicle's tires. Waffle tape is one such textured marking (Figure 2).

VDOT used large glass beads in line painting operations in the Lynchburg District from August 1993 to October 1995. VDOT also examined large glass beads in thermoplastic in an unsuccessful test installation. (One manufacturer of large beads has since stated that these beads are not effective in thermoplastic.) In 1994, VDOT began using waffle tape on interstates, limited access highways, and other high volume roads as determined by the district traffic engineers. Waffle tape was adopted because of its durability and high retroreflectivity.

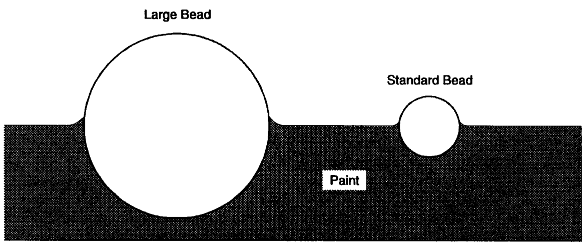

Figure 1A. Side view of large and standard beads

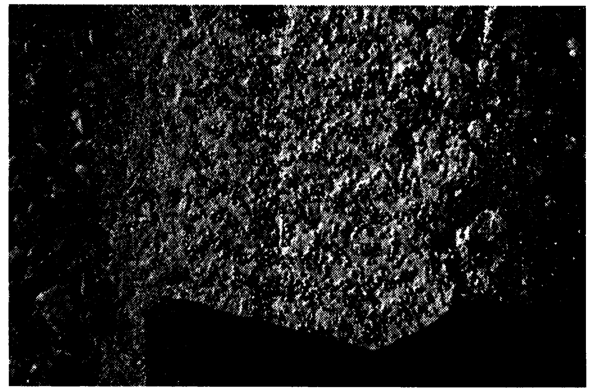

Figure 1B. Paint with large beads on road surface.

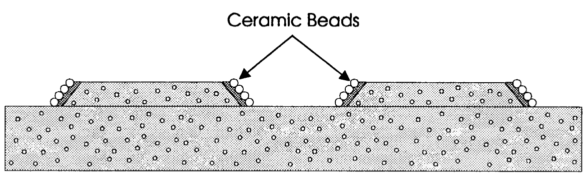

Figure 2A. Side view of waffle tape.

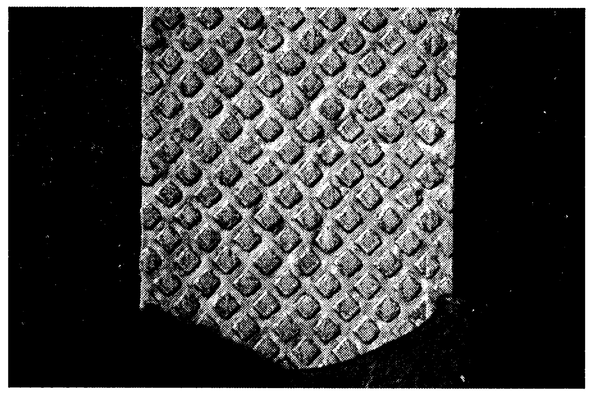

Figure 2B. Waffle tape on road surface.

VDOT is seriously interested in improving the visibility of pavement markings at night, especially during wet conditions. This research topic was rated as the highest priority by VDOT's Traffic Research Advisory Committee at its December 1992 meeting. The large beads and waffle tape now need to be evaluated for their effectiveness, especially under wet night conditions.

PURPOSE AND SCOPE

This study evaluated the performance of selected pavement marking materials for improving night visibility, especially under wet night conditions. The research included a series of field tests of pavement markings designed to enhance wet night retroreflectivity were installed and monitored. Data were collected at two sites along a primary arterial.

METHODS

Four tasks were conducted to accomplish the study's objective: (1) literature review, (2) field test development, (3) monitoring test sites, and (4) operational and subjective evaluations.

Literature Review

Literature on pavement markings was reviewed, specifically the literature on markings designed to provide improved wet night retroreflectivity.

Field Test Development

The researcher originally intended to develop some experimental patterns of conventional markings, and to modify newer markings. This approach was not used because we were unsuccessful in engaging the cooperation of the pavement marking manufacturers who were contacted. Additionally, at least one product of interest was under development and not yet available.

Two markings, latex paint with large beads and waffle tape, were selected. The markings were installed on Route 29 in Nelson County near Lovingston. The study team began collecting retroreflective data for paint in September 1994, and for tape in October 1994. The paint markings were installed on September 19, 1994, on a 1.9 km (1.2 mi) section on Route 29 southbound in Nelson County from Route 29 Business to Route 641. On the adjacent northbound section, waffle tape was installed on the skip lines in late September following a pavement overlay. The yellow and white edgelines were installed about 2 weeks later.

Monitoring Test Sites

Data were collected about every 4 to 8 weeks in October, December, January, March and April. Data were available before and after snowplow operations. The snowplow blade used was a carbide-tipped blade mounted on a dump truck with the weight of the blade resting on the pavement. The visual condition of the test pavement markings was observed. Retroreflectivity was measured with a retroreflectometer and by observation, and durability was assessed based on visible damage and the retroreflectivity of the markings. Retroreflectivity measurements are an objective way to quantify the nighttime brightness or visibility of pavement markings. The study team used the VDOT Materials Division's Mirolux 12 portable retroreflectometer for these measurements. Retroreflectivity is measured in millicandelas per meter squared per lux ($mcd/m^2/lx$). For each test site, the study team recorded 6 retroreflectometer measurements each for the white and yellow edgelines and the white skiplines (also called centerlines) in the beginning, middle, and end portions of the study sites. A total of 18 measurements were made at each site for each line. Drives through the test section were videotaped under wet night conditions. The monitoring period included at least one winter season in order to assess the impact of snowplowing on the markings. The t-test and F-test were used to test for significant differences in the means and standard deviations of the retroreflectivity measurements of the two markings, respectively.

Operational and Subjective Evaluations

The VDOT Lynchburg District traffic engineering personnel responsible for installing and maintaining pavement markings conducted the operational evaluation and recorded their findings. A subjective assessment of the markings was conducted separately by the research team and VDOT Lynchburg District traffic engineering personnel. These assessments were made under day, wet night, and dry night conditions.

RESULTS AND DISCUSSION

Literature Review and Ongoing Research

Because most of these pavement markings are relatively new, the literature available on their performance is limited. In a comparative study of large and standard glass beads in epoxy traffic paint, the New Jersey Department of Transportation concluded that the cost difference between the two beads was relatively low compared to the amount of increased wet night visibility offered by the large glass beads.[1] The University of North Carolina at Charlotte evaluated eight pavement marking materials for wet (and dry) night conditions, including lab and field tests.[2] Minimum marking luminance values (93 mcd/m^2 /lx for dry night and 180 mcd/m^2 /lx for wet night) were determined, and relative performances were examined. These values are not the recommended minimum values for practice, but are for research purposes only. The markings in the North Carolina study are different from those considered in this study.

Related Research Underway: All Weather Pavement Marking Study

In Section 6005(a) of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the Federal Highway Administration was mandated to study all-weather pavement markings (AWPM) and to evaluate the visibility, durability, and safety performance of AWPM. AWPM are defined as markings visible at night under dry conditions and under rainy conditions up to 0.64 cm (0.25 in) per hour of rainfall. Virginia is one of 17 states participating in this large-scale effort, which should provide useful findings on markings for wet night visibility. Of the three test sites in Virginia, one has epoxy, and two have epoxy with large beads. The author is the VDOT coordinator for this study.

Test Site Monitoring and Data Analysis

Retroreflectivity Readings

The retroreflectometer reading is an objective comparison of the brightness or retroreflectivity of markings under dry conditions only. Unfortunately, the retroreflectometer VDOT uses cannot measure the retroreflectivity of wet markings. In a comparison of the initial retroreflectivity readings, the waffle tape was two to three times more retroreflective than paint with large beads for each of the three lines (Table 1).

Table 1. Initial Retroreflectivity Measurements (mcd/m^2/lx)

	Skiplines	White Edgelines	Yellow Edgelines
Waffle Tape	738	647	487
Paint with Large beads	254	276	183
Ratio Waffle Tape: Paint with large beads	2.9	2.3	2.7

Figures 3, 4, and 5 display the retroreflective measurements over time for the skiplines, white edgelines, and yellow edgelines of the waffle tape and latex paint with large beads. There was a substantial drop in retroreflectivity between the January and March readings. Three snowplow events occurred between January and March (see Appendix). For both pavement markings, the percent of retroreflectivity loss was largest for the skiplines (33% for the tape and 39% for the paint); white edgelines experienced the next highest loss (19% for the tape and 24% for the paint), and yellow edgelines exhibited the least percent of loss (16% for the tape and 7% for the paint). The first snowplow event occurred between the December 1, 1994 and January 25, 1995 readings. From the graphs, the larger losses during this period were 7% for the white waffle tape edgeline and 16% for the yellow paint edgeline. There was a slight loss in retroreflectivity after the first snow plow event for the remaining lines. There was an insignificant 3% increase in the retroreflectivity of the yellow paint markings over the first three readings (the accuracy of the retroreflectometer is +/- 4%).

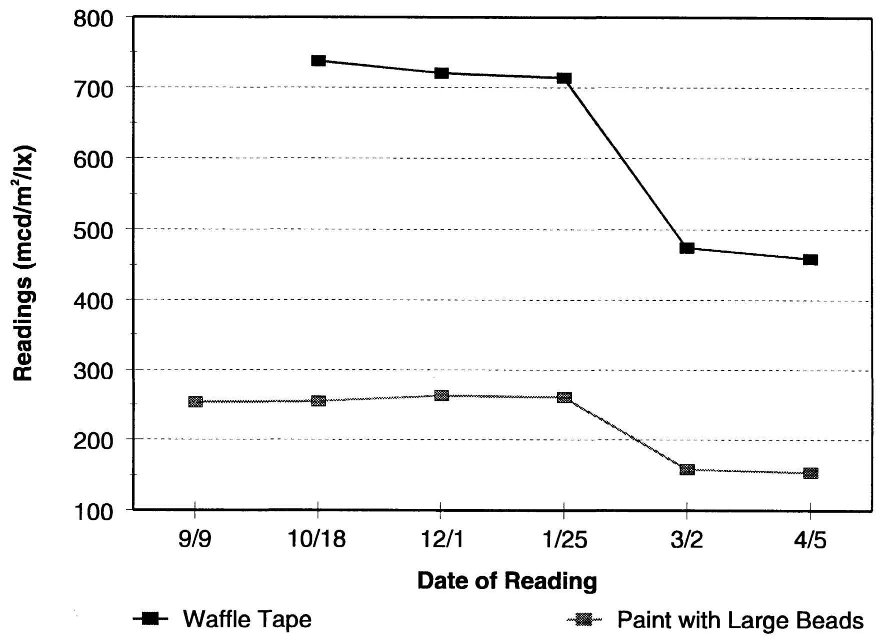

Figure 3. Retroreflective measurements of skiplines.

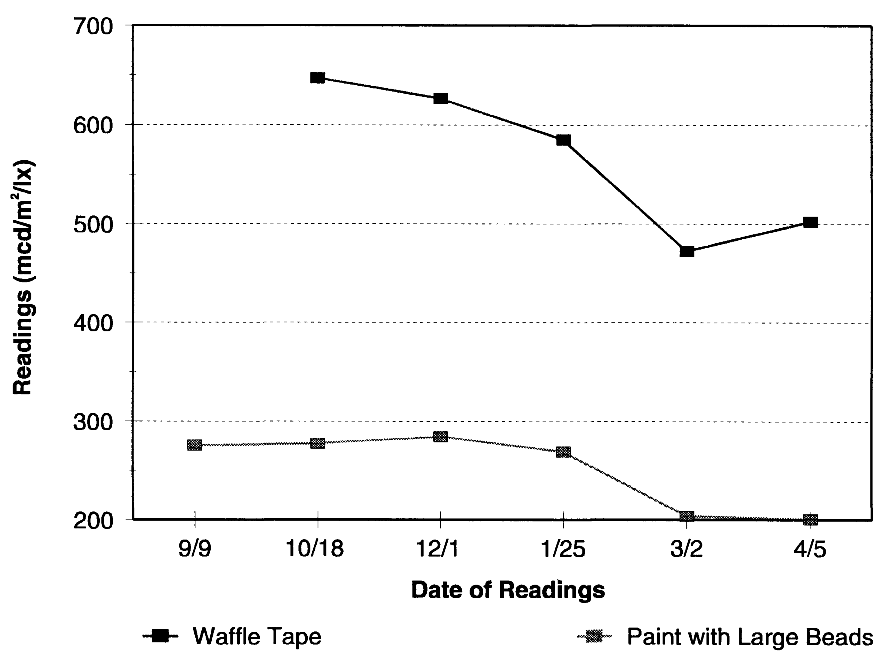

Figure 4. Retroreflective measurements of white edgelines.

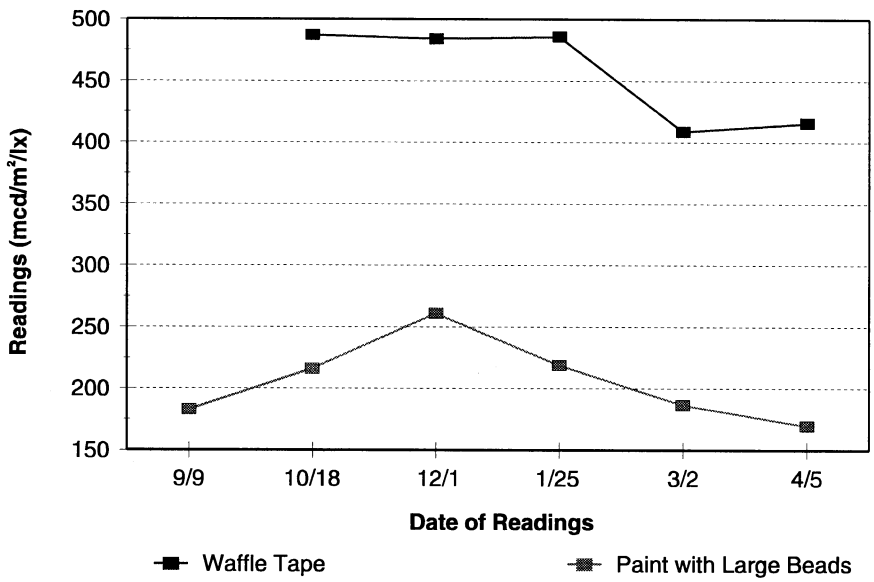

Figure 5. Retroreflective measurements of yellow edgelines.

The results of the F-test and t-test for the three lines of waffle tape and paint presented in Table 2 show that the variances in the retroreflectivity of the skipline for the tape and white edgeline for the paint were significantly different, and the means were significantly different for all three lines for the waffle tape and both white lines for the paint. The percentage decrease in retroreflectivity for all three lines ranged from 16 to 39% for both marking materials where significant differences exist. The order of percentage of retroreflectivity loss from highest to lowest by line type were skiplines, white edgelines, and yellow edgelines for both marking materials. The percentage retroreflectivity loss for the white paint lines was greater than for the white tape lines, whereas the yellow tape experienced a greater loss in retroreflectivity than the yellow paint line.

Subjective Evaluation

Paint with Large Beads

In the daylight, the white paint lines with large beads appeared to have a grayish color, even for a freshly painted line. The bead manufacturer attributed this color to a coating on the beads to promote adherence between the beads and the paint. The grayish color, although a minor concern, made the white line appear less bright than the white paint line with standard beads. Nighttime brightness or retroreflectivity under dry conditions appeared to be slightly lower than for lines painted with standard beads. A comparison between the initial retroreflectivity readings of lines with large beads at the study site (white lines - 269, yellow lines - 202) and paint with standard beads on Route 29 in Albemarle County (white lines - 311,

Table 2
Retroreflectivity Measurements Before and After the Snowplow Season (mcd/m^2 /lx)

	Skip lines					White Edgelines					Yellow Edgelines			
	Before	After	Diff	%Diff		Before	After	Diff	%Diff		Before	After	Diff	%Diff
Tape														
X	714	475	-293	-33		585	473	-112	-19		486	409	-77	-16
SD	36	67	31	86		60	52	-8	-13		34	44	10	32
F test	3.5 *					0.8					1.7			
t test	-23.1 *					-10.4 *					-10.2 *			
Paint														
X	261	158	-103	-39		269	204	-65	-24		202	187	-15	-7
SD	48	56	8	17		31	77	46	148		47	46	-1	-2
F test	1.4					6.2 *					1.0			
t test	-10.3 *					-5.8 *					-1.7			

Before readings were taken January 25. After readings were taken April 5.
X= mean
SD= standard deviation
*- significant difference between before and after measurements

yellow lines - 212) illustrated the lower brightness levels, especially for white lines (a difference of 15 percent). This lower brightness may have been caused by the problems the crews had with regulating the large bead-dispensing guns. It stands to reason that if the beads are dispensed unevenly, the retroreflectivity will be lower.

There appeared to be a slight increase in retroreflectivity levels for the large beads during light rain at night, compared to standard beads. For this study, "light rain" was defined subjectively. An upper-end light rain was a rate of rainfall sufficient to maintain a water film over standard markings, thus flooding out the marking (that is, the marking no longer retroreflects). However, in a heavy rain there is no difference between the visibility of paint with large or standard beads because both are flooded out. Paint with large beads tended to provide retroreflectivity slightly longer than standard beads before flooding out, and tended to recover more quickly as the rain slackened.

Waffle Tape

During the day, the white waffle tape appeared to be a brighter white than the paint with large beads. There was little difference in the appearance of the yellow lines for the two markings.

Under dry night conditions, the waffle tape white lines appeared much brighter than the white lines with large beads. Under the same condition, the yellow waffle tape was also brighter but there was less difference between the brightness of these two markings than between the white lines. The retroreflectivity readings supported the subjective evaluations. The waffle tape was 2 to 3 times brighter than the paint with large beads for both white and yellow markings.

Under wet conditions at night, the waffle tape was similar to the paint with large beads in terms of providing improved retroreflectivity, flooding out under similar rainfall conditions. It appeared that the waffle tape lines recovered slightly quicker than the paint lines with large beads.

Operational Evaluation

Paint with Large Beads

The Lynchburg district traffic engineering staff used large beads for all of the line painting performed by its crews from August 1993 through October 1995. There were two main operational concerns with using large beads compared to standard size beads: 1) lower productivity in painting operations, and 2) bead dispensing gun operations. Standard beads require 2.7 kg (6 lb) of beads per 3.8 l (1 gal) of paint whereas 5.4 kg (12 lb) of the large beads are used per 3.8 l (1 gal). As a result, large beads must be loaded twice as often as standard beads, and each loading takes about 15 percent longer (20 minutes instead of 15-18 minutes). Also, in order to have a day's supply of beads, additional large beads must be transported on supply trucks. The travel speed of the paint truck was reduced slightly from 16 km/h to 12.8-14.4 km/hr (10 mph to 8-9 mph). It was estimated that 1-1.5 hr or 10-15% of productive time is lost each day with the use of large beads.

The bead dispensing guns for the large beads required considerable repair and replacement, which also reduced productivity. The major problems with the guns were that the beads were not dispensed uniformly during painting, and the guns did not properly stop and start dispensing beads. Although the bead manufacturer assisted in troubleshooting, not all of the problems were resolved.

Waffle Tape

The skip lines were installed by the inlay method; that is, the marking was inlaid in fresh asphalt. The inlay method should require the marking crew either to work a few hundred meters behind the asphalt overlay operation, or at least to install the markings within three days. Otherwise, the overlay method is used. The tape on both edgelines was overlaid on the new asphalt about two weeks later. Because the waffle tape was installed by contractors, the installation was not monitored as closely as the painting. Nonetheless, no problems were reported by the contractor or VDOT staff.

Raised Pavement Markers: An Alternative

This study focused on pavement markings. Given the evaluation results thus far on waffle tape and paint with large beads, it is worth considering another alternative: raised pavement markers. VDOT has used both snowplowable raised pavement markers (rpm) and recessed pavement markers for several years on many interstates and other selected highways to enhance visibility at night and in bad weather. (VDOT has moved away from recessed markers because of poor installations, the development of potholes where the pavement groove is made in asphalt overlays, and other maintenance problems.) Nonsnowplowable raised markers are also installed in some work zones. Snowplowable raised markers in metal castings provide very good visibility under wet night and fog conditions. These markers are spaced at 24.6 m (80 ft) intervals and cost about $25 each, installed. Snowplowable rpms perhaps provide the best option for improving wet night visibility. In a report on the transportation needs of older drivers, the most frequent complaint about pavement markings was that they were not visible in bad weather, and rpms were the most often-suggested way to make night driving easier and safer.[3] The availability of funds for the maintenance of these rpms has been a concern for VDOT.

North Carolina uses nonsnowplowable rpms which cost about $2 each installed. The markers removed by plows are replaced each spring. The snowplowable markers initially cost about 10 times more than the nonsnowplowable rpms. The disadvantage of the nonsnowplowable markers is that, because of snow plowing, a portion of them may not be on the road during the snow season, which is about 3 months of the year. VDOT has considered trying nonsnowplowable rpms in the Suffolk District, where snowfall is minimal and the removal of these markers by snow plows would be infrequent.

Cost-Effectiveness

Cost-effectiveness was measured as cost per linear meter per retroreflectivity per year of service life; or:

Cost-Effectiveness = initial cost ($per linear meter)/relative value of retroreflectivity reading/service life (yr)

Retroreflectivity was measured relatively; that is, the paint with large beads was assigned a value of one, which gave the waffle tape a value of 2.5 (because it was 2.5 times more retroreflective than paint with large beads -- see Table 1). The initial cost of the waffle tape versus paint with large beads was about $5.69 per linear meter (lm) ($1.75/lf) versus $0.16 per lm ($0.05/lf), respectively. The service life for waffle tape is typically 6 yrs compared to 1 yr for paint with large beads. The cost-effectiveness measure for the waffle tape is $0.38/linear m/ retroreflectivity/yr, versus $0.16/linear m/retroreflectivity/yr for paint with large beads.

The initial cost of snowplowable rpms is about $25. The metal castings typically have a service life as long as the pavement (average 8 years), while the retroreflective lens may have a service life of about three years. The cost to replace the retroreflective lens twice during the service of the metal casting is about $4. The total cost over an eight-year service life is about $29. The cost per year over an eight-year service life of a snowplowable rpm is $3.60. Because of the high initial cost of snowplowable rpms, highway agencies have supplemented centerline and laneline markings with snowplowable rpms every 25 m (80 ft) to develop an all weather delineation system at low cost.[4] The cost of such a system with paint markings is $620 to $930 per lane kilometer ($1,000 to $1,500 per lane mile).[4] At a 25 m (80 ft) spacing, the cost per linear m per year over an eight-year service life is about $0.15/linear m/yr ($0.05/lf/yr) with snowplowable rpms on a laneline. Because snowplowable rpms are used to supplement markings and not as a replacement for markings, it is not appropriate to directly compare them with the study markings.

Although rpms are more retroreflective than waffle tape, the retroreflectometer used in this study could not accurately measure the retroreflectivity of the snowplowable rpms, so they cannot here be compared objectively to waffle tape and paint with large beads. In this simplified analysis, snowplowable rpms appear cost-effective without accounting for retroreflectivity. A more detailed analysis would include the entire delineation system and retroreflectivity of the marker.

Limitations of the Study

A limited number of study sites and lane miles were investigated in detail for retroreflectivity measurements. However, the subjective evaluation performed by the study team covered about 20.9 km (13 miles) of a combination of paint with large beads and waffle tape in about a 50-50 mix. Moreover, the subjective evaluation performed by the Lynchburg District staff was not limited to the study sites but covered a substantial portion of the district over a 28-month period (2 1/2 paint seasons). Similarly, the operational evaluation covered all of the paint with large bead markings applied in the district over a 27-month period. Thus the results are not based solely on the limited study sites.

CONCLUSIONS

1. When compared to paint with standard beads, the waffle tape provided improved retroreflectivity during light rain at night and recovered quicker after flooding out. Similarly, paint with large beads provided marginally improved retroreflectivity during light rain at night and also recovered quicker after flooding out. Both markings flooded out at about the same time under heavier rainfall.

2. The white paint lines with large beads appeared grayish during the day and provided lower retroreflectivity during dry conditions than the standard beads for white and yellow markings.

3. The operational problems encountered in the application of paint with large beads (including 10-15 percent lower productivity and problems with the bead dispensing guns) are not offset by the marginal visibility enhancements during periods of light rain.

4. The benefits provided by the waffle tape during light rain do not appear to justify the use of waffle tape solely for wet night visibility.

5. Snowplowable raised pavement markers appear to be cost-effective and are very good for enhancing visibility during wet night conditions.

RECOMMENDATIONS

1. The VDOT Traffic Engineering Division should continue to use and maintain snowplowable rpms to enhance visibility during wet night conditions.

2. VDOT's Research Council and Traffic Engineering Division should continue to monitor the AWPM study being conducted by FHWA.

3. The Suffolk District should consider testing nonsnowplowable raised pavement markers as a low-cost alternative to improve visibility during wet night conditions where snow plowing occurs infrequently. The Research Council is prepared to provide technical assistance for this.

ACKNOWLEDGEMENTS

The VDOT Lynchburg District traffic engineering staff helped provide information on the district's operational experience and subjective evaluation of the test markings. Jan Kennedy is thanked for data collection, compilation and analysis, and for proofreading drafts of the report; Steve Blackwell for data collection; the Lynchburg district pavement marking section for providing information and traffic control during field data collection; Robert McCarty (FHWA), Marvin Tweedy (Lynchburg District), John Miller, Charles Stoke, Amy O'Leary, and Mike Perfater for peer review of the draft report; and finally Gary Mawyer for editing and preparing the final manuscript.

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APPENDIX
DATA COLLECTION AND SNOW PLOWING LOG AT ROUTE 29, LOVINGSTON

DATA COLLECTION DATES

September 19, 1994 (paint only)
October 18, 1994
December 1, 1994
January 25, 1995
March 2, 1995
April 5. 1995

DATE	PRECIPITATION	ACCUMULATION (mm)	
1/6-7/95	Sleet/Freezing Rain	24	
1/28/95	Sleet, Snow, Freezing Rain	100	
1/29/95	Sleet/Freezing Rain	25	
1/30-31/95	Snow/Sleet	125	
2/3-4/95	Sleet, Freezing Rain , Ice, Snow	125	
2/15-16/95	Sleet	50	
	TOTAL	449	(18 in)

1 mm = 0.04 in