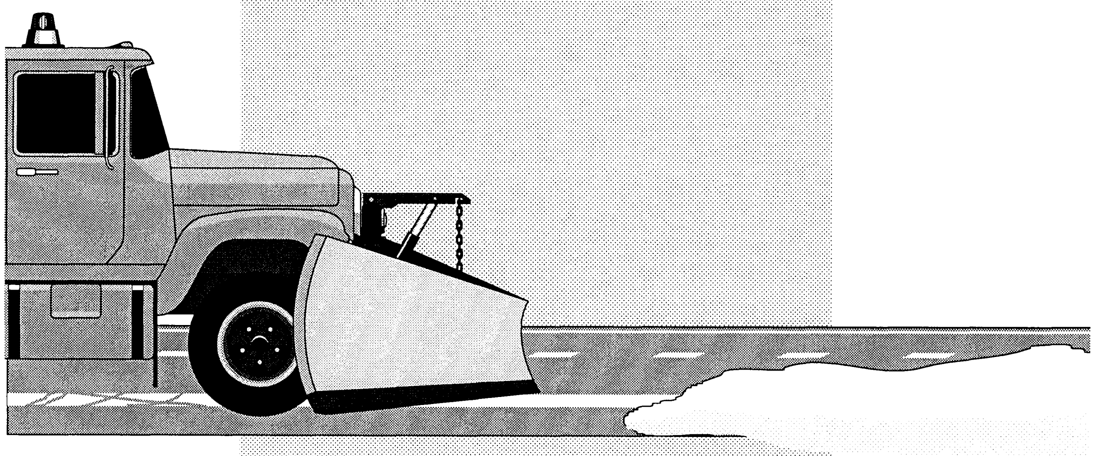
FINAL REPORT

INVESTIGATION OF THE IMPACT OF SNOW REMOVAL ACTIVITIES ON PAVEMENT MARKINGS IN VIRGINIA



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16. Abstract

Snow removal activities resulted in substantial damage to pavement markings in Virginia over the last 2 years. Typically, the estimates of the extent of pavement marking damage are based on the observations of the staff of the Virginia Department of Transportation (VDOT). For example, it was estimated that about half of the pavement markings statewide were damaged during the 1993-94 winter and that replacement costs were $8 million.

The objective of this study was to obtain accurate data on the pavement marking damage caused exclusively by carbide-tipped blades. Data were collected at 22 study sites on interstate highways and principal arterials because of the prevalence of a variety of pavement markings and the designation of these roads as high-priority routes for snow removal. Three types of pavement markings-latex, paint, thermoplastic, and waffle tape-were assessed for damage.

For the study sites, damage caused by snow plows during the 1994-95 winter were estimated to be between $100,100 and $137,700 for waffle tape and $400 to $600 for paint, for a total of $100,500 to $138,300. The estimated retroreflectivity loss of 10 to 15 percent for both markings represented the majority of the costs. About $25,000 of the damage to waffle tape was for markings that were plowed from the roadway. There was no evidence that thermoplastic markings incurred much damage. This is probably because there were few or no instances where ice bonded to the pavement markings. It is believed that thermoplastic marking damage is greatest when this bonding occurs. Moreover, there is less confidence in the before data for thermoplastic markings.

Based on data gathered at the study sites, the estimated statewide cost of damage caused by snow plows was between $1.58 and $2.26 million for waffle tape and between $1.06 and $1.59 million for paint, for a total of between $2.64 and $3.85 million. It should be noted, however, that the 1994-95 winter was relatively mild compared to a typical winter in Virginia.

The study recommends that VDOT (1) take measures to protect its investment in pavement markings from snow plow damage, (2) comprehensively assess pavement marking damage caused by other maintenance activities, and (3) designate the inlaid method as the primary installation method for waffle tape.

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

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

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ABSTRACT

Snow removal activities resulted in substantial damage to pavement markings in Virginia over the last 2 years. Typically, the estimates of the extent of pavement marking damage are based on the observations of the staff of the Virginia Department of Transportation (VDOT). For example, it was estimated that about half of the pavement markings statewide were damaged during the 1993-94 winter and that replacement costs were $8 million.

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Based on data gathered at the study sites, the estimated *statewide* cost of damage caused by snow plows was between $1.58 and $2.26 million for waffle tape and between $1.06 and $1.59 million for paint, for a total of between $2.64 and $3.85 million. It should be noted, however, that the 1994-95 winter was relatively mild compared to a typical winter in Virginia.

The study recommends that VDOT (1) take measures to protect its investment in pavement markings from snow plow damage, (2) comprehensively assess pavement marking damage caused by other maintenance activities, and (3) designate the inlaid method as the primary installation method for waffle tape.

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INTRODUCTION

By delineating the travel lanes, pavement markings provide warning and guidance to motorists without diverting their attention from the roadway. Pavement markings are especially helpful at night, when reduced visibility creates a greater need for guidance information. Damaged markings may not adequately provide this important information to drivers. In recent years, the Virginia Department of Transportation (VDOT) has received more complaints about the quality of its pavement markings than for any other traffic control device.

The Governor's Commission on Government Reform (GCGR) proposed the following recommendation relative to snow plow blade damage to pavement markings:

> *Recommendation TR45.* Obtain more accurate data concerning the damage caused exclusively by carbide-tipped blades. Various test sections of roadways should have a "before and after" snowstorm pavement marking assessment performed.

Snow removal activities caused substantial damage to pavement markings in Virginia over the last 2 years. Typically, the estimates of the extent of the damage are based on the best guess of VDOT district traffic engineering (DTE) staff from their observations. For example, it was estimated that about half of the pavement markings statewide were damaged during the 1993-94 winter; estimated replacement costs were between $7.6 and $8.4 million.[1]

To enhance the visibility and extend the service life of markings, VDOT recently began using a durable waffle pattern preformed tape (6-year service life), mainly on limited access highways. The waffle tape is designated as Type B-VI by VDOT and costs about $0.53 per linear meter ($1.75 per linear foot) as compared to $0.02 per meter ($0.05 per foot) for paint and $0.06 per meter ($0.20 per foot) for thermoplastic. To achieve the full service life of all pavement markings, there is much interest in minimizing damage from snow removal activities.

PURPOSE AND SCOPE

The objective of this study was to obtain accurate data on the damage to pavement markings caused exclusively by carbide-tipped blades. Data were collected at 22 study sites along interstate highways and principal arterial corridors because of the prevalence of a variety of pavement markings and the designation of these roads as high-priority routes for snow removal.

The three types of pavement markings—latex paint, thermoplastic, and waffle tape—that are common along these corridors were examined for damage.

METHODS

This research consisted primarily of a series of before and after field tests at sites where carbide-tipped blades were used in snow removal activities along selected test sections of roadway. Four tasks were conducted to accomplish the study's objective: (1) literature review and survey of state departments of transportation (DOTs), (2) selection of study sites, (3) before and after data collection, and (4) data analysis.

Literature Review and Survey of State DOTs

A computerized literature search was conducted through the Transportation Research Information Service (TRIS) to identify literature related to the subject of this study. A questionnaire survey was sent to maintenance engineers in 34 state DOTs located north of Virginia's southern border and 5 Canadian provinces to learn about their experiences with snow removal activities and related damage to pavement markings. The survey was conducted in collaboration with two other researchers conducting studies concerning GCGR recommendations on snow removal activities.[2,3] Of the 19 questions, 10 dealt with snow plow use, 7 with anti-icing and deicing applications, and 2 with pavement marking damage.

Selection of Study Sites

Initially, the sample size needed for statistical significance at a 95 percent confidence interval was calculated using the following equation (the level of significance for a two-tailed test is 0.05)[4]:

$$n = 4pq/B^2$$

where n = sample size

p = proportion of successes (markings not damaged)

q = proportion of failures (markings damaged)

B^2 = proportion of acceptable error (0.05).

If p and q are conservatively assumed to be 0.5, which is in line with reports of damage by DTE staff, then the sample size required is about 400. Because the deadline allowed only a 5-month period for the study, the determination of the sample size was driven by the limited time and resources available as opposed to the desired level of significance.

Site selection was concentrated along interstate highways in the Bristol, Salem, and Staunton Districts and Route 29 in the Lynchburg District. These sites were selected because of the larger snowfall these areas of Virginia receive. The length of a study site ranged from about 1.6 to 11.3 km (1 to 7 mi) depending on the section length available and the pavement marking material present.

There were 22 sites chosen: 14 with waffle tape, 5 with thermoplastic, and 3 with latex paint. This division reflected the facts that (1) few paint sections were on the interstate, where durable markings are typically used; (2) waffle tape replaced thermoplastic as the durable marking at many sites in 1994; and (3) the author believed that use of waffle tape was a major influence in the development of the GCGR recommendation that prompted this study. As a secondary effort and for comparative purposes, the waffle tape installed in 1992, the thermoplastic installed in 1993, and the use of rubber snow plow blades in one area were reviewed. Table 1 is a list of the study sites.

Before and After Data Collection

Route 29, Lovingston

The author currently has a study underway to evaluate the visibility of pavement markings, specifically waffle tape and large beads in latex paint, at night under wet conditions.[5] The study sites for this project are on Route 29 near Lovingston. The study team began collecting retroreflective data for paint in September 1994 and for tape in October 1994. Data were also collected about every 4 to 8 weeks, including in December, January, March, and April. Thus actual before and after snow plow operations data were available.

The data collection dates for both markings (unless otherwise noted) and the dates of snow plowing were as follows:

Markings	Snow Plowing
September 19, 1994 (paint only)	
October 18, 1994	
December 1, 1994	January 6-7, 1995
January 25, 1995	January 28-31, 1995
	February 3-4, 1995
	February 15-16, 1995
March 2, 1995	
April 5, 1995	

The data from these study sites were invaluable to this research effort.

TABLE 1
DESCRIPTION OF STUDY SITES[1]

Site Number	District/County	Route Direction	Location	Length (km)
Tape 1	Salem/Roanoke	I-81 SB	MP 137.7-139.8	3.4
Tape 2	Salem/Roanoke	I-81 SB	MP 130.4-137.6	11.6
Tape 3	Salem/Roanoke	I-81 NB	MP 131.2-137.6	10.3
Tape 4	Salem/Roanoke	I-81 NB	MP 141.6-147.2	9.0
Tape 5	Bristol/Washington	I-81 SB	MP 6.8-8.0	1.9
Tape 6	Bristol/Washington	I-81 NB	MP 5.6-6.9	2.1
Tape 7	Bristol/Washington	I-81 SB	MP 0.0-3.0	4.8
Tape 8	Bristol/Washington	I-81 NB	MP 19.7-23.0	5.3
Tape 9	Staunton/Augusta	I-81 NB	MP 207.1-210.5	5.8
Tape 10	Staunton/Augusta	I-64 WB	MP 87-93	9.7
Tape 11	Culpeper/ Albemarle	I-64 WB	MP 126.7-129.7	4.8
Tape 12	Culpeper/ Albemarle	I-64 EB	MP 126.7-131.2	7.2
Tape 13	Culpeper/Fluvanna	I-64 EB	MP 131.2-137.3	9.8
Tape 14	Lynchburg/ Campbell	Rte 29 SB	SCL of Lynchburg- 2.5 Mi S of SCL	4.0
Thermoplastic 1	Bristol/Washington	I-81 NB	MP 15-17	3.2
Thermoplastic 2	Staunton/Augusta	I-81 NB	MP 214.3-217	4.3
Thermoplastic 3	Staunton/Augusta	I-64 EB	MP 88-94	9.7
Thermoplastic 4	Culpeper/Fluvanna	I-64 EB	MP 137.3-143.6	10.1
Thermoplastic 5	Lynchburg/ Campbell	Rte 29 SB	0.5 Mi N of Rte 738 - Rte 24	6.9
Paint 1	Salem/Roanoke	I-81 SB	MP 139.8-141.5	2.7
Paint 2	Staunton/Augusta	I-81 NB	MP 210.9-213.8	4.7
Paint 3 (large beads)	Lynchburg/ Campbell	Rte 29 SB	Rte 24 to 2.4 Mi S of Rte 24	3.9

Tape 1992 installation	Bristol/Washington	I-81 SB	MP 0.0-3.0	4.8
Tape rubber blades	Lynchburg/ Pittsylvania	Rte 29 SB	0.6 Mi N of Rte 903 - 0.3 Mi N of Rte 1400	4.5
Paint (large beads) rubber blades	Lynchburg/ Pittsylvania	Rte 29 SB	Rte 40- 0.6 Mi N of Rte 903	3.9
Thermoplastic 1993 installation	Culpeper/ Albemarle	I-64 WB	MP 107-114	11.2

[1]Tape 1 through Paint 3 constitute the 22 primary study sites. The last four sites are secondary study sites.

Study Sites

Three types of data were collected: (1) retroreflectivity measurements of pavement markings, (2) pavement marking condition based on durability and color, and (3) the extent to which pavement markings were damaged and the related costs. Data were obtained from VDOT files and field studies. The first snowfall of the 1994-95 winter occurred before the study team was able to collect field data at any study sites. Data on installation of the pavement markings and pavement marking condition before the first snowfall were obtained from the DTE sections.

Retroreflectivity Measurements

Retroreflectivity measurements provide an objective means of quantifying the nighttime brightness or visibility of pavement markings. The study team used the VDOT Materials Division's Mirolux 12 portable retroreflectometer to obtain these measurements. Data collected on Route 29 near Lovingston as part of another pavement marking study[5] being conducted by the author and other sources of pavement marking data were used for the before retroreflectivity readings. 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. At two sites, additional measurements were made on sections where markings were damaged by snow plows.

Durability and Color

Pavement marking condition ratings for durability and color that were adopted for the Federal Highway Administration's (FHWA) evaluation of all-weather pavement markings were used.[6] In the FHWA evaluation, durability was measured by the percentage of marking material remaining on the pavement, with 10 equaling 100 percent and 0 being 0 percent. Color visual effectiveness is a measure of how visible and definite in color the markings are using a scale from 0 to 10. A combination of drive-through and closeup observations for all of the test sections were made to assess the condition of the pavement markings. Data available on the marking condition before and after the recent winter storms were obtained from the VDOT district offices. Most data collected by the study team were for the after period.

Pavement Marking Damage Assessment and Estimated Costs

Two types of pavement marking damage were assessed: (1) damage necessitating replacement of markings plowed from the roadway, and (2) retroreflectivity loss on markings that remained intact. The amount of damaged pavement markings to be replaced was estimated for each site. The following guidelines identifying damaged markings for replacement were established to expedite and develop consistency in the estimates: (1) for edgelines, at least a 6.3-m (20-ft) section should be damaged; (2) for skiplines, at least half the line should be damaged; and (3) for both edgelines and skiplines, at least 50 percent of the marking material should be off the pavement. The loss in retroreflectivity caused by snow plows was also determined by comparing the before and after retroreflectivity readings. Drive throughs of all the study sites and closeup observations were performed to assess the condition of the pavement markings. The costs of both types of damage were estimated for the study sites and statewide.

Monitoring Snow Removal Activity

Area headquarters and residency personnel provided information on the snow removal activity and weather conditions at the study sites.

Data Analysis

The before and after data were compared to determine the magnitude and extent of damage to the various pavement markings. The percentage of markings damaged was the primary measure of performance. Other measures included the changes in the condition rating and retroreflectivity. The most detailed analysis was conducted for the retroreflective readings.

Retroreflective Readings

Two statistical tests were performed to measure the change in retroreflectivity of the pavement markings before and after snow plowing: (1) comparing the variances (or standard deviations) to examine the effects of snow plow damage in increasing the variability or range in the retroreflective measurements, and (2) comparing the means to measure the change in the retroreflective measurements before and after the snow plowing.[4] Because their position on the roadway may be a factor in the change in retroreflectivity, the markings were divided into three groups: skiplines, white edgelines, and yellow edgelines. First, the variances in the retroreflective measurements before and after snow plowing were compared using the F test to determine if the change in variance (i.e., an increase after snow plowing) was statistically significant. The level of significance of this one-tailed test was 0.05 for a 95 percent confidence interval. The F value was compared with the F value for the statistical upper limit of the confidence interval (2.02 for white and 2.07 for yellow) to determine if the difference in variances of the retroreflective measurements before and after snow plowing was statistically significant. The appropriate t test for comparing the difference in the mean retroreflective measurements was selected based on the results of the F test. If the variances were equal, then a t test with a pooled standard deviation was used. Otherwise, the Aspin-Welch test was used.

RESULTS AND DISCUSSION

Literature Review and Survey of State DOTs

The computerized literature search failed to reveal any research studies dealing with the topic of this study. In informal conversations with several state traffic engineers at a Transportation Research Board committee meeting, the consensus was that pavement marking damage from snow plows was an unfavorable circumstance that had become accepted as normal operating practice. This would explain, in part, why there was no literature available on this subject.

With regard to the survey questionnaire, responses were received from 23 agencies for a response rate of 59 percent. When asked to assess the extent of pavement marking damage caused by snow plow blades, 3 agencies (2 referred to raised pavement markers) stated that damage was substantial, 5 stated moderate, 11 minor, and 1 nonexistent. Two agencies stated that most marking damage was a result of the sanding action of abrasives. When asked what actions, if any, were taken to reduce pavement marking damage, 2 agencies noted that they were experimenting with placing pavement markings in grooves to protect the markings from snow plows—this response appear to be related to raised pavement markers.

Data Analysis

Before and After Retroreflectivity Measurements on Route 29, Lovingston

Figures 1 and 2 display the retroreflective measurements for waffle tape and latex paint with large beads, respectively. The substantial drop in retroreflectivity between the January and March readings is obvious. For both pavement markings, the percentage of retroreflectivity loss was largest for skiplines (33 and 39 percent for tape and paint, respectively); white edgelines had the next highest loss (19 and 24 percent for tape and paint, respectively), and yellow edgelines had the least loss (16 and 15 percent for tape and paint, respectively). The first snow plowing occurred between the December and January readings. From the graphs, the larger losses during this period were 7 percent for the white waffle tape edgeline and 16 percent for the yellow paint edgeline. There was a slight loss in retroreflectivity following the first snow plowing for the

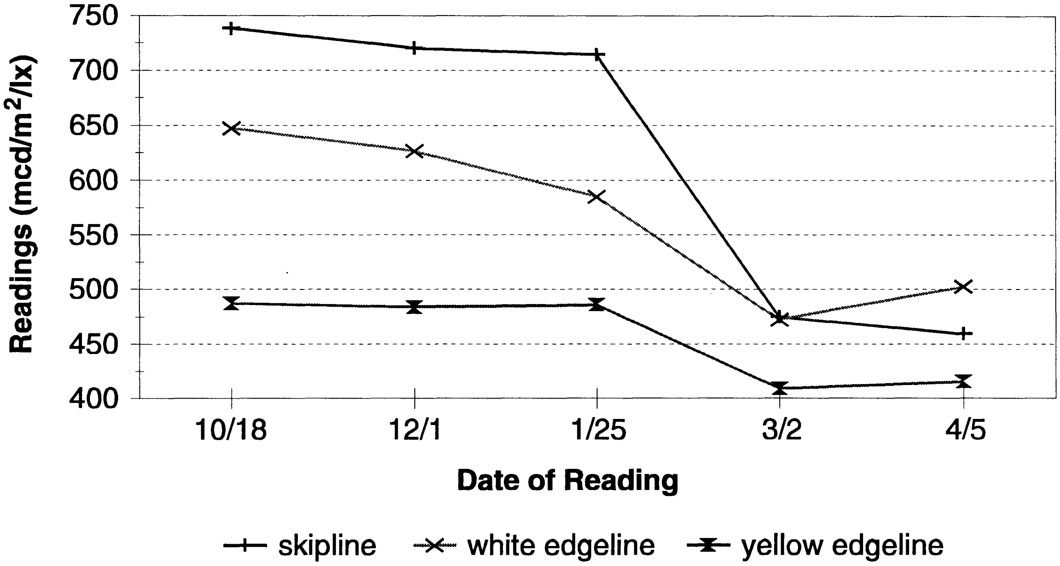

FIGURE 1. RETROREFLECTIVE MEASUREMENTS FOR WAFFLE TAPE

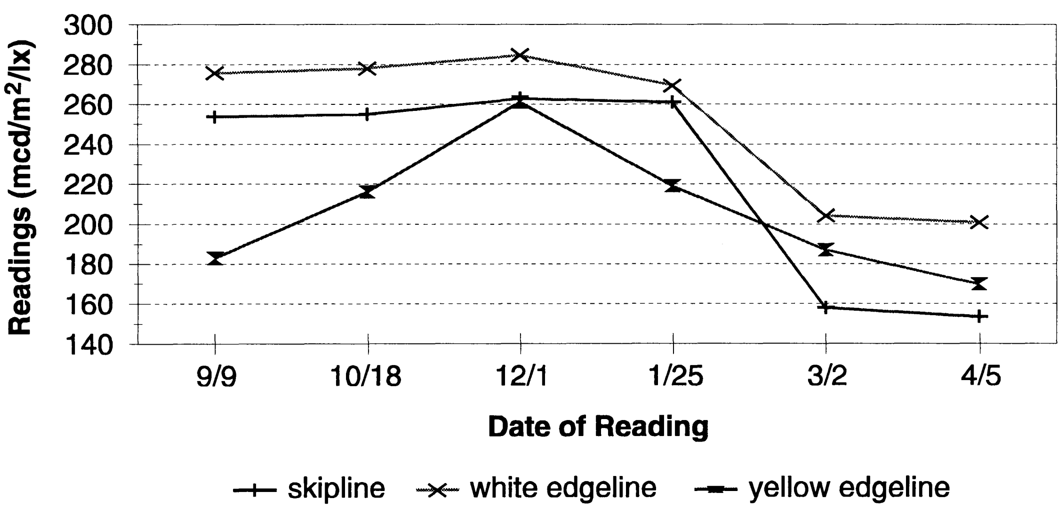

FIGURE 2. RETROREFLECTIVE MEASUREMENTS FOR LATEX PAINT WITH LARGE BEADS

remaining lines. Although the retroreflectivity of the yellow paint markings increased inexplicably over the first three readings, the increase was not important to this study.

The results of the *F* test and *t* test for the three lines of waffle tape and paint presented in Table 2 show that (1) the variances in the skipline for the tape and the edgeline for the paint were significantly different, and (2) 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 percent for both marking materials where significant differences existed. The order of percentage of retroreflectivity loss from highest to lowest by line type were skiplines, white edgelines, and yellow edgelines for both markings.

TABLE 2
RETROREFLECTIVE MEASUREMENTS AT ROUTE 29 LOVINGSTON (MCD/M²/LX)

	Skiplines				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	11	32
F	3.5				0.8				1.7			
t	-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	1.4				6.2				1.0			
t	-10.3				-5.8				-1.7			

Study Sites

Before Retroreflectivity Measurements

Because the study team was unable to collect retroreflective data before the first snowfall of the year, the before measurements used were based on the data collected on Route 29 in Lovingston, Southeastern Association of State Highway and Transportation Officials (SASHTO) field evaluation data,[7] data from the Institute of Transportation Research Education (ITRE),[8] and expert opinions.[9,10] Without actual before readings, the usefulness of this report is contingent upon the selection of before readings that are reasonable and realistic.

The original plan was to use initial readings, i.e., readings taken just after installation of the markings, as before data. However, there was some concern that these readings might not be appropriate because loss in retroreflectivity may have occurred between the installation and the start of the snow season. The first question was: Should initial readings or readings taken just before the snow season be used? A comparison of the initial reading and the January reading at the Route 29 Lovingston site showed that the retroreflective measurements of the white and yellow markings were changed by -6.0 and 0 percent, respectively, for waffle tape and 0 and +19.6 percent, respectively, for paint with large beads. Since these differences as well as some differences from the SASHTO data did not reveal any trend, the initial readings were chosen for use as the basis for the before data.

The next question was: What values should be used for the before readings? Table 3 displays the information used to choose the before readings. Data from Route 29 at Lovingston, SASHTO (for thermoplastic markings), and ITRE were weighted heavily. The expert opinions and test site data were used to modify the weighted data to ensure that the before readings were

TABLE 3
INITIAL RETROREFLECTIVITY MEASUREMENTS (MCD/M²/LX)

Source	Waffle Tape	Paint	Thermoplastic
Route 29 Lovingston	White = 690 n = 108 Yellow = 490 n = 54	With large beads: White = 265 n = 108 Yellow = 183 n = 54	
SASHTO[7]	White = 864 Yellow = 670	White = 333 Yellow = 262	White = 445 Yellow = 262
ITRE study[8]		White = 224 Yellow = 206	
Expert opinions[9,10]		White = 150-250 Yellow = 130-150	White = 300-400 Yellow = 200-300
Initial readings used	White = 690 Yellow = 550	White = 224 Yellow = 206 With large beads: White = 265 Yellow = 183	White = 400 Yellow = 200

reasonable. For example, the yellow waffle tape reading of 490 at Lovingston was increased to 550 because the after readings at half the study sites exceeded 490. The before readings are conservative; that is, they likely represent the lower end of the expected before readings. Although this approach appears reasonable and logical, it is acknowledged that variability exists in the initial retroreflectivity of pavement markings.

Durability and Color Assessment

There was no information available to assess the durability and brightness of the pavement markings for the before period. Consideration was given to assuming that the before conditions should be rated as a 10 because new markings should be rated highest. However, there was no evidence to support this assumption. Thus, because of these uncertainties, only the after ratings made by the study team were recorded.

Practically all of the study sites had very high ratings for color, that is, 9 or 10. If the pavement markings were intact, then the color rating was very good. Therefore, the study team concluded that color rating was not a useful indicator to differentiate between the conditions of pavement markings, and it was not used as a measure of performance.

The results of the durability assessment are provided in Table 4 for all sites that did not rate a 10 for all three line markings. Site Paint 2 had the lowest overall rating by a substantial margin because the pavement had numerous longitudinal cracks. Site Paint 6 had some minor pavement cracking. At all 6 waffle tape sites listed in Table 4, adhesive failure of the waffle tape prompted by snow plows was the cause of damage. Site Tape 13 had the greatest amount of snow plow damage.

TABLE 4
DURABILITY RATING

Site	White Skiplines	Yellow Edgelines	White Edgelines	Overall
Paint 1	9.0	9.0	8.6	8.9
Paint 2	5.2	5.3	4.0	4.8
Paint 6	7.0	8.0	9.0	8.0
Tape 1	10.0	9.0	6.4	8.5
Tape 2	10.0	9.0	7.5	8.8
Tape 3	10.0	9.6	9.7	9.8
Tape 11	9.4	8.4	8.4	8.7
Tape 12	7.0	9.0	8.0	8.0
Tape 13	5.0	7.0	6.0	6.0

All other sites were rated as 10 for all three lines.

Comparison of Before and After Retroreflectivity Measurements

Waffle Tape. The data summary and results of the F and t tests for the waffle tape sites are shown in Table 5. For these 8 sites, the standard deviation of the skipline readings at 3 sites and the standard deviation of both of the edgelines at 4 sites were significantly different. Overall, the standard deviation increased by 22, 50, and 34 percent for the skiplines, white edgelines, and yellow edgelines, respectively. Similarly, the mean readings for yellow edgelines at 6 sites for both skiplines and white edgelines and 3 sites for yellow edgelines were significantly different. Overall, the mean decreased by 23, 27, and 19 percent for skiplines, edgelines, and yellow edgelines, respectively. The periodic, even cyclic, shearing of the top layer of glass beads from the pavement marking by the snow plow is likely the cause of the increase in variance and decrease in retroreflectivity. Depending on the angle of the sunlight, the periodic shearing was noticeably visible by dark spots in the marking line. This shearing effect was visible for other marking types as well.

Thermoplastic Markings. Because an actual sample of initial retroreflective measurements was not available, statistical tests were not conducted for the paint and thermoplastic study sites. The mean percentage loss in retroreflectivity for the 4 study sites was 10, 6, and 26 percent, respectively, for skiplines and white and yellow edgelines (see Table 6). If these values are compared with those for Site Thermoplastic 1 where no snow plowing occurred, it may be possible to distinguish between retroreflectivity loss caused by normal wear and loss due to snow plowing. The percentage mean losses were about the same or less for the study sites for the white markings. No readings were available as a control for the yellow markings. Therefore, based on the study data, it appears that thermoplastic markings incurred no additional damage by the snow plows. It is possible that retroreflectivity loss caused by snow plows was incurred, but this cannot be proven because of the assumptions that had to be made for the initial retroreflectivity measurements.

Latex Paint. In Table 6, the mean percentage loss in retroreflectivity for the 3 study sites was 17, 40, and 31 percent for skiplines and white and yellow edgelines, respectively. There was no control for latex paint. The shearing of the glass beads by the snow plows appeared continuous along some paint sections.

Snow Plowing Log. The record of the number of times snow plowing was done at the study sites and the type and amount of accumulation are provided in the Appendix. An analysis to examine the relationship between the number of times snow plowing was done and the percentage of loss in retroreflectivity revealed no distinct pattern.

TABLE 5
RETROREFLECTIVITY MEASUREMENTS FOR WAFFLE TAPE SITES (MCD/M²/LX)

	Skiplines					White Edgelines					Yellow Edgelines				
Site	Mean Before	Mean After	Diff	% Diff	*t*	Mean Before	Mean After	Diff	% Diff	*t*	Mean Before	Mean After	Diff	% Diff	*t*
Tape 1	690	595	-95	-14	5.84*	690	621	-69	-10	4.20*	550	464	-86	-16	7.76*
Tape 2	690	596	-94	-14	6.14*	690	494	-196	-28	13.14*	550	536	-14	-3	1.33
Tape 9	690	442	-248	-36	17*	690	416	-274	-40	2*	550	375	-175	-32	15.71*
Tape 10	690	617	-73	-11	4.78*	690	442	-248	-36	15.11*	550	431	-119	-22	0.94
Tape 11	690	579	-111	-16	1	690	526	-164	-24	1.17	550	529	-21	-4	0.14
Tape 12	690	482	-208	-30	12.88*	690	426	-264	-38	2.19*	550	441	-109	-20	0.85
Tape 13	690	522	-168	-24	1.20	690	632	-58	-8	0.36	550	373	-177	-32	1.53
Tape 14	690	429	-261	-38	2.16*	690	460	-230	-33	13.98*	550	418	-132	-24	11.78*
		Mean	-157	-23			Mean	-188	-27			Mean	-104	-19	
		SD	70	10			SD	79	12			SD	58	11	

	Skiplines					White Edgelines					Yellow Edgelines				
Site	Mean Before	Mean After	Diff	% Diff	*F*	Mean Before	Mean After	Diff	% Diff	*F*	Mean Before	Mean After	Diff	% Diff	*F*
Tape 1	61	80	19	31	1.72	61	83	22	36	1.85	44	42	-2	-5	0.91
Tape 2	61	54	-7	-11	0.78	61	40	-21	-34	0.43	44	32	-12	-27	0.53
Tape 9	61	39	-22	-36	0.41	61	117	56	92	3.68*	44	43	-1	-2	0.96
Tape 10	61	53	-8	-13	0.75	61	83	22	36	1.85	44	75	31	70	2.91*
Tape 11	61	87	26	43	2.03*	61	121	60	98	3.93*	44	94	50	114	4.56*
Tape 12	61	77	16	26	1.59	61	118	57	93	3.74*	44	75	31	70	2.91*
Tape 13	61	111	50	82	3.31*	61	87	26	43	2.03*	44	67	23	52	2.32*
Tape 14	61	96	35	57	2.48*	61	84	23	38	1.90	44	44	0	0	1.00
		Mean	14	22			Mean	31	50			Mean	15	34	
		SD	23	37			SD	25	41			SD	20	46	

Overall average % diff -23
Overall SD 11

* = significantly different.

TABLE 6
RETROREFLECTIVITY DATA FOR PAINT AND THERMOPLASTIC SITES (MCD/M²/LX)

	Skiplines				White Edgelines				Yellow Edgelines			
Site	**Mean Before**	**Mean After**	**Diff**	**% Diff**	**Mean Before**	**Mean After**	**Diff**	**% Diff**	**Mean Before**	**Mean After**	**Diff**	**% Diff**
Paint 1	224	164	-60	-27	224	114	-110	-49	206			
Paint 2	224	195	-29	-13	224	149	-75	-33	206	114	-92	-45
Paint 6	265	238	-27	-10	265	165	-100	-38	183	152	-31	-17
Mean		199	-39	-17		143	-95	-40		133	-62	-31
Overall average of % diff	-29											
Overall SD of % diff	13											
Thermo 2	400	367	-33	-8	400	401	1	0	200	154	-46	-23
Thermo 3	400	367	-33	-8	400	371	-29	-7	200	151	-49	-25
Thermo 4	400	316	-84	-21	400	342	-58	-15	200			
Thermo 5	400	396	-4	-1	400	384	-16	-4	200	142	-58	-29
Mean		362	-38	-10		375	-25	-6		149	-51	-26
Overall average of % diff	-13											
Overall SD of % diff	10											
Thermo 1 (control)	400	366	-34	-9	400	357	-43	-11				

increased slightly. The increase in retroreflectivity in the white and yellow edgelines for the tape can be attributed to the actual before readings being higher than the estimated before readings. For the other markings, the loss in retroreflectivity ranged from 12 to 39 percent. Snow plows were used only two times during the winter at this site, which may be another factor in the high after readings. According to area headquarters personnel, about 40 percent more chemicals were used with the rubber blades than would have been used with carbide-tipped blades. The study team was not able to determine if the loss in retroreflectivity was caused by the plowing or the chemicals (abrasives). Based on this limited information, the results of using rubber blades to reduce snow plow damage to pavement markings are inconclusive.

Retroreflective Measurements of Damaged Waffle Tape

A small sample of retroreflective readings was made on yellow waffle tape that contained noticeable damage, such as scrape marks. The mean retroreflective reading was 300, 46 percent below the estimated before reading, and the standard deviation was 110, 2.5 times the before value. The changes in both the mean and standard deviation were statistically significant not only when compared with the estimated before readings but also when compared with after readings at the same study site.

Tape Installed in 1992 in the Bristol District

Waffle tape was installed in 1992 on I-81 in Washington County from MP 0.0 to 3.0, southbound, in the Bristol District. The waffle tape on the skiplines had been through three winters; the first two winters had above normal winter precipitation. The retroreflective readings are presented in Table 7. For the skiplines, the mean reading of 375 was much lower than the assumed before reading (47 percent lower). Because this waffle tape was installed 2 years before the tape was installed at the study sites, it was not surprising that this was the lowest tape reading recorded. Also, the variance was lower than that of the assumed before readings.

Thermoplastic Markings Installed in 1993

The thermoplastic markings on I-64 in Albemarle County west of Charlottesville were examined after being in service for two winters. The percentage loss in retroreflectivity was 27, 36, and 76 for skipline and white and yellow edgelines, respectively. This loss was statistically significant for all three lines. The markings still appeared in good condition, although, based on the retroreflectivity readings, the yellow edgeline was borderline on needing to be replaced.

TABLE 7
RETROREFLECTIVE MEASUREMENTS AT SECONDARY SITES (MCD/M^2/LX)

	Skiplines				White Edgelines				Yellow Edgelines			
	Before	**After**	**Diff**	**%Diff**	**Before**	**After**	**Diff**	**%Diff**	**Before**	**After**	**Diff**	**%Diff**
Route 29 Chatham Rubber Blades												
Tape												
X	690	501	-189	-27	690	724	+34	+5	550	556	+6	0
SD	61	54	-7	-11	61	102	+41	+67	44	67	+23	+52
F	0.78				2.78				2.32			
t	-1				1.37				0.36			
Paint												
X	270	238	-32	-12	270	165	-105	-39	180	152	-28	-15
SD	30	30	0	0	30	24	-6	-25	18	39	+21	117
F	1.0				0.64				4.76			
t	-4.2				-14				-2.9			
I-81 Bristol SB: Washington County Waffle Tape Installed in 1992												
X	690	375	-315	-47								
SD	61	46	-15	-25								
F	0.57											
t	-21											
I-64 Culpeper WB: Albemarle County Thermoplastic Installed in 1993												
X	400	291	-109	-27	400	257	-143	-36	200	124	-76	-38
SD		29				29				9		
t		-39				-52				-90		

Cost Assessments for the Study Sites

An important aspect of this evaluation was the placement of a monetary value on the pavement marking damage caused by snow plow activity. The discussion on this aspect is subdivided by the type of damage: markings that were plowed from the roadway and, thus, required replacement, and retroreflectivity loss of markings that were intact.

Marking Replacement Costs

There were no test sites marked with thermoplastic and paint that required replacement. The secondary site on I-64 with thermoplastic installed in 1993 required the replacement of about 32 m (105 ft) of yellow edgeline at a cost of $21. The amount of pavement marking that needed to be replaced at each study site and the associated costs are shown in Table 8. The replacement costs ranged from $53 to $13,414 for 5 tape sites. It is estimated that 4,325 m (14,180 ft) of waffle tape required replacing at a total cost of $24,815.

TABLE 8
ESTIMATED REPLACEMENT NEEDS AT STUDY SITES

	Skiplines (m)	White Edgelines (m)	Yellow Edgelines (m)	Total (m)	Estimated Total Cost
Tape 1			149	149	$858
Tape 2			842	842	4,830
Tape 11	9	0	0	9	53
Tape 12	387	12	587	987	5,661
Tape 13	1,125	275	938	2,338	13,413
Total	1,522	287	2,516	4,325	$24,815

Retroreflectivity Loss

The loss in retroreflectivity for all lines where snow plowing occurred (the mean overall loss) between the before and after period for waffle tape, paint, and thermoplastic averaged 23, 29, and 13 percent, respectively. Although there were five snowfalls, no plowing was done at the 5 study sites in the Bristol District; only chemicals were used to control the snow. These sites were used as control sites to measure the percentage decrease in retroreflectivity expected without snow plowing. The overall mean loss in retroreflectivity for waffle tape and thermoplastic (white markings only) at these sites without snow plowing was 6 and 10 percent, respectively. The overall mean loss for thermoplastic white markings was 8 percent. To obtain the estimated overall mean retroreflectivity loss caused by snow plowing, the overall mean retroreflectivity loss that occurs without snow plowing is subtracted from the overall mean retroreflectivity loss with snow plowing. Therefore, about 17 percent of the loss in retroreflectivity for waffle tape could be attributed to snow plowing. If it is assumed that the marking cost is directly proportional to the retroreflectivity, then the value of this retroreflectivity loss is 17 percent of the cost of the marking for the waffle tape. Figures 3A and 3B show waffle tape damage by snow plowing.

For the thermoplastic markings, there was actually a smaller loss with snow plowing than without plowing, but the difference (2) was small. Therefore, the percentage of retroreflective loss was 0 for thermoplastic. It can be concluded that based on the information gathered in this study, this past winter's snow plowing activity did not result in appreciable damage to thermoplastic markings. This finding tends to agree with the prevailing opinion within VDOT that thermoplastic marking damage is greatest when ice bonds to the pavement marking and a snow plow simultaneously removes the marking and ice. Since there was no substantial ice bonding this past winter, thermoplastic marking damage was minor. Also, the author places less confidence in the before retroreflective readings for thermoplastic markings because these readings were based on data from other sources.

It was difficult to estimate the loss in retroreflectivity to latex paint caused by snow plow activities because there was no control site available where snow plowing did not occur. Photographic evidence, Figures 4A and 4B, illustrate that paint markings were damaged by snow plow activity. A control site would have been useful in estimating the extent of retroreflectivity loss expected at non-plowed sites. Figure 2 provides evidence of the sharp decrease in retroreflectivity after snow plowing at the Route 29 Lovingston site. It is clear that snow plowing caused a substantial loss in retroreflectivity. The three paint study sites yielded an overall retroreflectivity loss of 29 percent: this is comparable to the 32 percent overall retroreflectivity loss at the Route 29 site in Lovingston. If it is conservatively assumed that half the loss would have occurred without snow plowing, then 15 percent loss in retroreflectivity is assumed.

Given that the 17 percent value for the overall mean percent retroreflectivity loss for waffle tape is indeed an estimate, the margin of error on the upper end could be lowered by reducing the loss estimate to 15 or even 10 percent. This would take into account the varying conditions across the state and the extenuating circumstances of the study that are discussed later. A 15 percent loss in retroreflectivity translates into a cost of $112,890 and $620 at the study sites for waffle tape and paint, respectively. A 10 percent retroreflectivity loss for the study sites yields costs of $75,260 and $420 for waffle tape and paint, respectively.

Therefore, total damage estimates, i.e., replacement costs and retroreflectivity loss (rounded to the nearest hundred), range from $100,100 to $137,700 for waffle tape sites, $400 to $600 for paint sites, and $100,500 to $138,300 for all study sites.

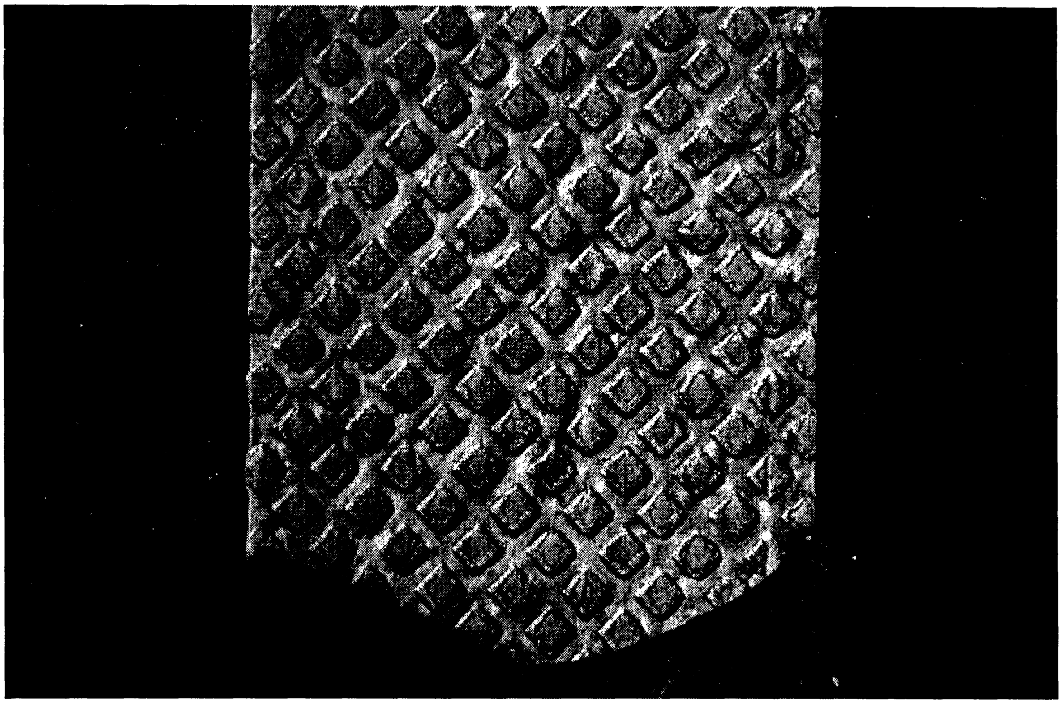

FIGURE 3A. WAFFLE TAPE BEFORE SNOW PLOWING

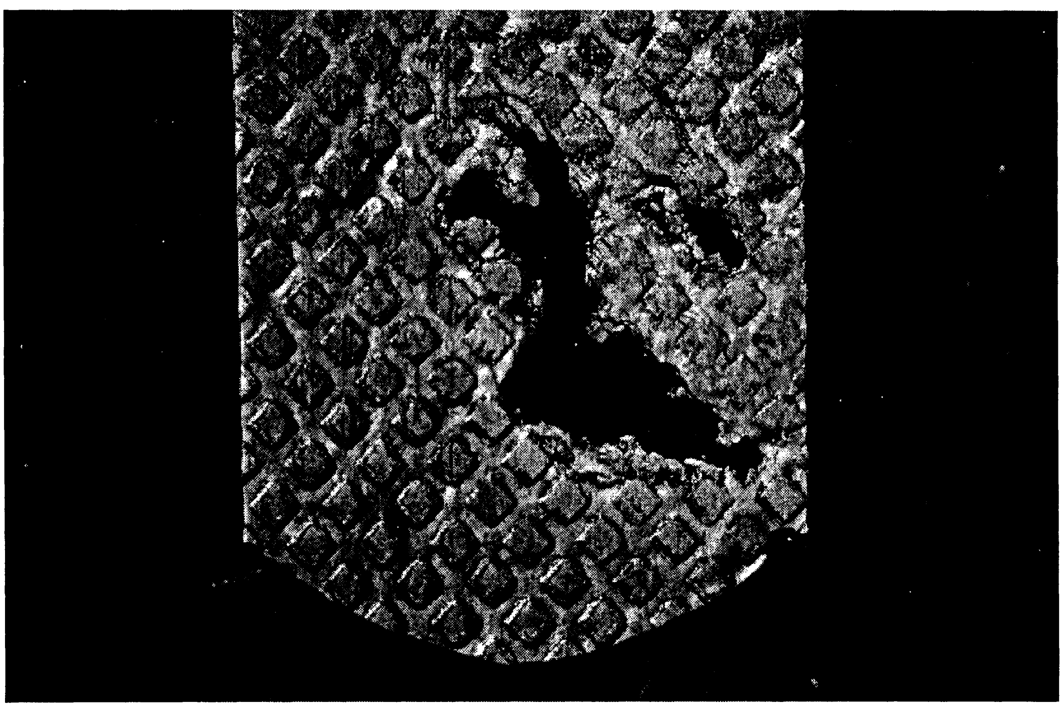

FIGURE 3B. WAFFLE TAPE AFTER SNOW PLOWING

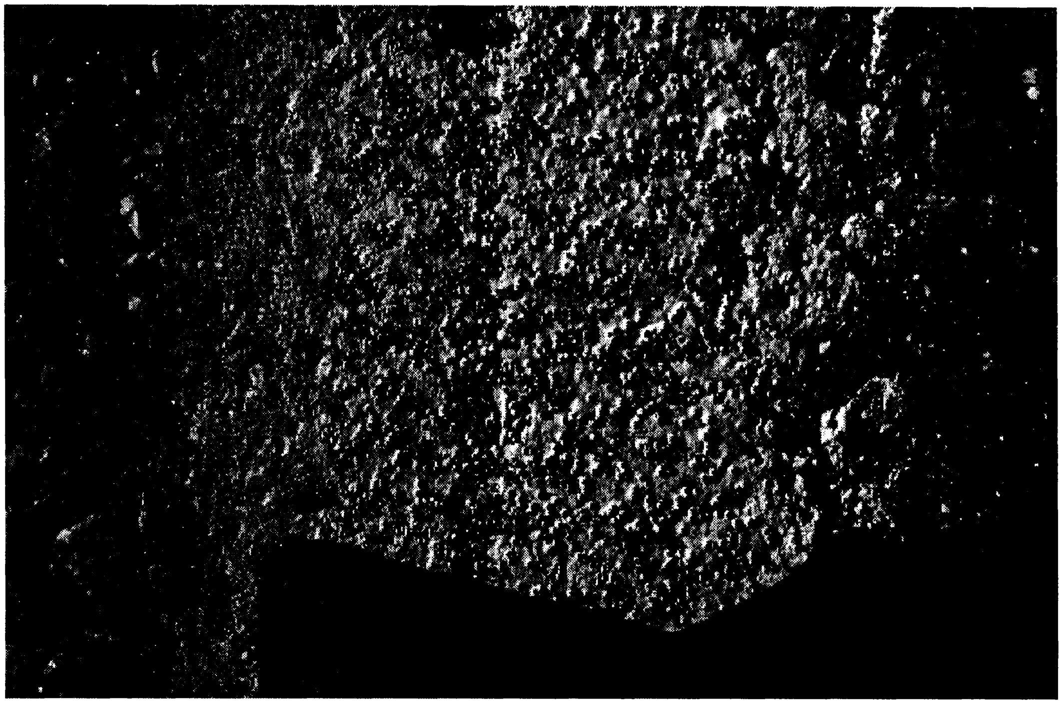

FIGURE 4A. PAINT WITH LARGE BEADS BEFORE SNOW PLOWING

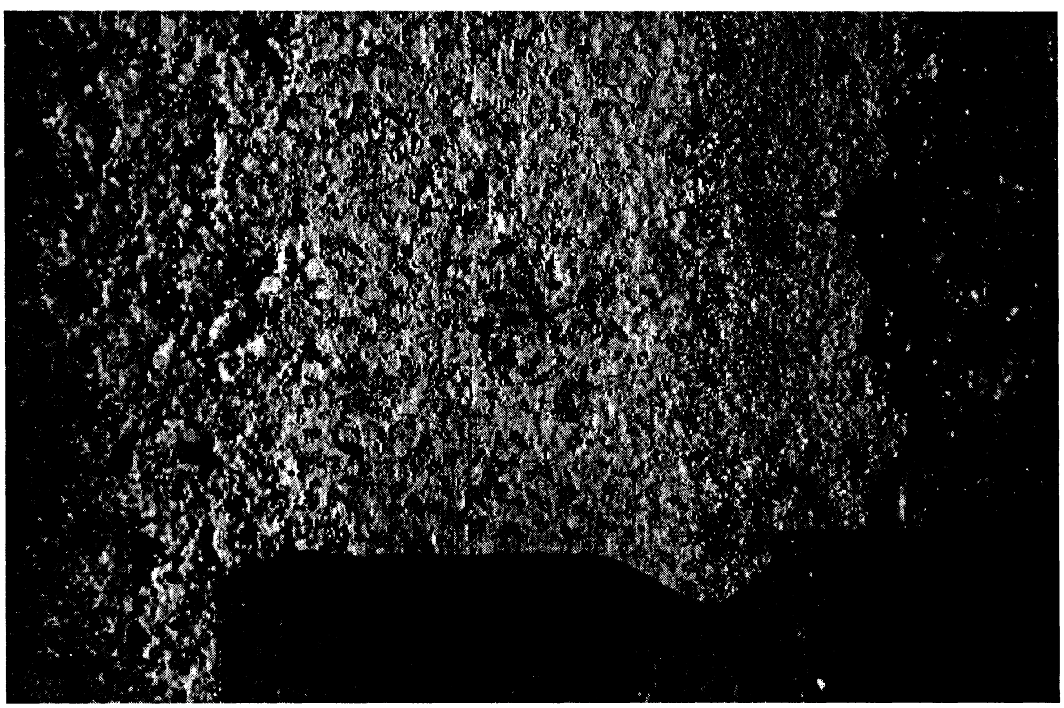

FIGURE 4B. PAINT WITH LARGE BEADS AFTER SNOW PLOWING

Statewide Estimate of Damage Costs

Replacement Costs

The waffle tape warranty necessitates that VDOT districts periodically assess the locations where damaged tape needs to be replaced. Table 9 presents the information that was available from the districts. Statewide, a total of about 38,125 m (125,000 ft) of waffle tape was identified to be in need of replacement. The Salem District accounted for about 64 percent of the total amount, and the Lynchburg District was a distant second, accounting for 18 percent of the total. These numbers are consistent with the fact that these two districts installed the most waffle tape. Estimating the cost of the damaged markings that require tape replacement following a relatively mild winter would yield a total cost of about $219,000 for replacing 38,125 m (125,000 ft) of tape.

TABLE 9
WAFFLE TAPE REPLACEMENT REPORT: ESTIMATED LINEAR METERS FOR REPLACEMENT

District	Skiplines	White Edgelines	Yellow Edgelines	Ramps and Gore Areas	Total
Bristol	387	1,738	473	244	2,842
Culpeper	1,522	287	1,526	8	3,343
Northern Va					1,830
Lynchburg[1]					5,740
Salem 4 in	580	2,899	10,838	5,670	
8 in	1,482	339	419	2,143	
Total					24,370
Statewide					38,125

[1]The subtotal from the other districts was subtracted from the statewide total estimated by 3M (see Table 10) to obtain the Lynchburg District estimate; Lynchburg district staff viewed this value as reasonable.

Retroreflectivity Loss and Total Costs

If the estimated retroreflectivity loss at the study sites is applied to the areas in the state where snow plowing was performed this winter, then an estimate can be made of the statewide cost for tape damage. If retroreflectivity losses of 15 and 10 percent are used, the estimated costs are $2.04 million and $1.36 million, respectively. Conservatively then, it is estimated that the total statewide damage to waffle tape from snow plows (replacement cost plus retroreflectivity loss) was between $1.58 and $2.26 million.

In FY 94, VDOT allocated $10.63 million to line painting statewide. If a loss in this investment of 15 percent is attributed to snow plowing, $1.59 million is the estimated cost of the retroreflectivity loss. This percentage is in line with the high end of the conservative estimate for waffle tape. If a more conservative estimate of 10 percent is used, then the estimated cost of the retroreflectivity loss is $1.06 million. Therefore, based on these estimates, the range of retroreflectivity loss statewide is $1.06 to $1.59 million for paint.

If the estimated range of costs of the damaged tape and retroreflectivity loss for the tape and paint are summed, the total estimated cost of pavement marking damage caused by snow plowing range from $2.64 to $3.85 million. Because there remains a good deal of uncertainty in developing this range, these estimates are probably conservative.

Waffle Tape Installation Methods and Damage

There are two methods for installing waffle tape: overlay or inlay. For overlay, the tape is overlaid on existing pavements or on new pavements more than 3 days old. The alternative is to inlay the tape in fresh asphalt; typically, the marking crew is a few hundred feet behind the asphalt operations. This operation involves unrolling the tape in the desired location and pressing it into the asphalt using a drum roller. According to the results of an inventory performed by 3M (shown in Table 10), most of the damaged markings were overlaid. The fact that less than 1/100 of 1 percent of the 1.22 million meters (4 million feet) of inlaid tape was damaged compared to 2.1 percent of the overlaid tape is evidence that the inlaid installation should be the method of choice. Although improper installation was probably a major factor in many of the failures, it is clear that the potential for failure is substantially less with the simpler installation and stronger pavement-tape bond that is made with the inlaid method.

TABLE 10
WAFFLE TAPE DAMAGE REPORT BY 3M: ADHESIVE FAILURE DUE TO SNOW PLOWS

Installation Method	Million Linear Meters	Linear Meters Damaged	% Damaged
Inlay	1.22	92	<0.01
Overlay	1.83	38,033	2.08
Total	3.05	38,125	1.25

Improper installation may be the result of several factors, including marginal weather conditions, inadequate eradication of old markings, inadequate cleaning of pavement before applying the adhesive, improper adhesive application, and improper compaction/tamping of the tape after it is applied to the adhesive. In fact, Salem District staff, based on their experiences with overlay installation, is convinced that all waffle tape should be inlaid and is planning to proceed in that manner.

The secondary study section with tape installed in 1992 was inlaid. All of the tape was intact without visible damage after three winters. Of the 14 study sites with waffle tape, only the 4 sites in Bristol were inlaid. Five other waffle tape study sites were on new pavement; therefore, there could have been an opportunity to inlay the tape.

Extenuating Circumstances

In measuring damage caused by snow removal, the study team looked for clues to determine whether damage might have been caused by snow plows, abrasives, or other sources. The limited investigations revealed that snow plows were likely the predominant cause of damage. It is acknowledged that other causes of damage were possible along the test sections; the extent of such damage, though expected to be small, is unknown.

Although this study estimated damage to pavement markings caused by carbide-tipped snow plow blades, snow plows also scrape and damage the pavement; the extent of this damage is unknown. Raised pavement markers are also damaged by snow plows. Further, certain VDOT maintenance activities other than snow plowing, e.g., machining shoulders, result in pavement marking damage. To examine pavement marking damage comprehensively, other maintenance activities should be considered.

CONCLUSIONS

Of the numerous activities that VDOT performs, it appears that a conflict exists between two of them: snow plowing that is done an average of 5 to 10 days per year statewide and providing pavement markings for road delineation. In FY 95, VDOT allocated $23.16 million for pavement markings under maintenance replacement. Measures that will help VDOT to protect this substantial investment by considering means to reduce the pavement marking damage caused by snow plowing appear warranted. Recommendations on these means are presented in the final report of another GCGR study conducted by the Virginia Transportation Research Council (VTRC).[12]

The findings of this study led to the following conclusions:

1. It is estimated that in winter 1994-95, damage caused by snow plows at the 22 study sites cost between $100,100 and $137,700 for waffle tape and $400 and $600 for paint, for a total of $100,500 to $138,300. Most of these costs were for retro-reflectivity losses of 10 to 15 percent for the two types of markings. About

$25,000 of the damage to waffle tape was for replacing markings that were plowed from the roadway

2. Using the data gathered at these study sites as a basis, it is estimated that the 1994-95 statewide costs of damage caused by snow plows amounted to $1.58 to $2.26 million for waffle tape and $1.06 to $1.59 million for paint, for a total of $2.64 to $3.85 million. Within these ranges, $219,000 was for replacement of damaged waffle tape that was plowed from the roadway. The remaining cost was for a retroreflectivity loss of 10 to 15 percent for both markings.

3. There was no evidence that thermoplastic markings incurred any appreciable damage. This finding tends to agree with the prevailing opinion within VDOT that thermoplastic marking damage is greatest when ice bonds to the pavement marking and a snow plow simultaneously removes the marking and ice. Without such bonding, damage is minor. Also, the author places less confidence in the before retroreflective readings for the thermoplastic markings because these readings were based on data from other sources.

4. It is the author's view that the estimates given are conservative considering the mildness of the 1994-95 winter compared to typical winters in Virginia.

RECOMMENDATIONS

1. VDOT should take measures to protect its investment in pavement markings. Recommendations made in two other VTRC studies[3,12] should provide some measures to be considered by VDOT. Further review or research on damage caused by snow plowing should also include damage to other items such as the pavement, raised pavement markers, and other roadway features.

2. VDOT's Traffic Engineering Division should designate the inlay method as the primary installation method for waffle tape. For example, on pavement overlay projects where waffle tape will be installed, the contract should specify that the waffle tape be inlaid.

3. VDOT should comprehensively assess pavement marking damage caused by other maintenance activities and implement measures to eliminate it. The Traffic Engineering and Maintenance Divisions should jointly lead this effort. Other traffic control devices should also be considered.

ACKNOWLEDGMENTS

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REFERENCES

1. Cottrell, B. H. Jr. Memorandum to J. L. Butner, Virginia Department of Transportation. August 15, 1994.

2. Roosevelt, D. S. *Work Plan: Evaluation of Urethane Snow Plow Blades as an Alternative to Rubber Blades.* February 1995. Charlottesville: Virginia Transportation Research Council.

3. Wyant, D. C. *Work Plan: Exploring Ways to Prevent Bonding of Ice to Pavement.* February 1995. Charlottesville: Virginia Transportation Research Council.

4. Choi, S. C. *Introductory Applied Statistics in Science.* Prentice-Hall, 1978

5. Cottrell, B. H. Jr. *Work Plan: Evaluation of Pavement Markings for Improved Visibility During Wet Conditions at Night.* February 1994. Charlottesville: Virginia Transportation Research Council.

6. Migletz, J., Graham-Migletz Enterprises. Letter to author. December 2, 1994.

7. Kentucky Transportation Center. *National Transportation Product Evaluation Program (NTPEP) SASHTO Regional Test Facility. Volume I. Summary of Results of 1993 Field and Laboratory Evaluations of Pavement Marking Materials.* August 1994. AASHTO.

8. Attaway, R. W., and Adeleke-Sheidun, P. O. *Pavement Marking Materials Program.* January 1990. Research Triangle Park: University of North Carolina, Institute for Transportation Research and Education.

9. Hacker, L., Materials Division, Virginia Department of Transportation. Telephone conversation with author. March 13, 1995

10. Attaway, R. W., Institute for Transportation Research and Education, University of North Carolina. Telephone conversation with author. May 23, 1995.

11. Leigh, J. P., 3M. Letter to Lynwood Butner, Virginia Department of Transportation. April 14, 1995.

12. Roosevelt, D. S. *Final Report: Evaluation of Urethane Snow Plow Blades as an Alternative to Rubber Blades.* August 1995. Charlottesville: Virginia Transportation Research Council.

APPENDIX: SNOW PLOWING LOG/RECORD

DATE	PRECIPITATION	ACCUMULATION (mm)	TOTAL (mm)
RTE 29, LOVINGSTON			
1/6-7/95	SLEET/FREEZING RAIN (FR)	24	
1/28/95	SLEET, SNOW, FR	100	
1/29/95	SLEET/FR	25	
1/30-31/95	SNOW/SLEET	125	
2/3-4/95	SLEET, FR, ICE, SNOW	125	
2/15-16/95	SLEET	50	449
I-81 SALEM (HANGING ROCK AHQ)			
1/6/95	SLEET/SNOW	19	
1/28-31/95	SNOW	200	
2/15/95	ICE	6	225
I-64 & I-81, AUGUSTA COUNTY			
1/6-7/95	FR/SNOW	100	
1/28/95	SNOW	100	
1/29/95	SNOW	200	
1/30/95	SNOW	100	
1/31/95	SNOW	150	
2/3/95	SNOW	25	
2/4/95	SNOW/SLEET	300	
2/5/95	SNOW	50	
2/15/95	FR/SNOW	75	
3/9/95	SNOW	50	1150
I-64 CULPEPER DISTRICT (ZION CROSSROADS AHQ)			
1/28-29/95	SNOW	138	
1/30/95	SNOW	100	
2/4/95	SNOW/SLEET	50	
2/15/95	SNOW	50	338
RTE 29, CAMPBELL COUNTY (TIMBERLAKE AHQ)			
1/30/95	SNOW	100	
2/1/95	SNOW/FR	50	
2/4/95	SNOW/SLEET	50	200
RTE 29, PITTSYLVANIA COUNTY - CHATHAM			
1/6/95	FR	38	
1/29-30/95	SNOW OVER SLEET	37	75

BRISTOL DISTRICT HAD NO PLOWING