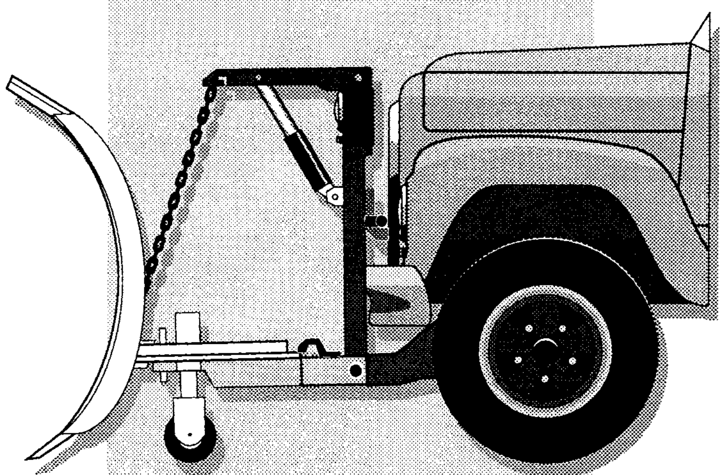
FINAL
REPORT

EVALUATION OF URETHANE AND CARBIDE-TIPPED BLADES ON WHEEL-SUPPORTED SNOW PLOWS



D. S. ROOSEVELT
Research Scientist

B. H. COTTRELL, JR.
Senior Research Scientist

VIRGINIA TRANSPORTATION RESEARCH COUNCIL

Technical Report Documentation Page

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16. Abstract

The objective of this study was to evaluate the performance of urethane and carbide-tipped snow plow blades on wheel-supported plows. Their performance was compared to that of VDOT's standard blade arrangement: carbide-tipped blades on plows without wheels. Performance was measured by the extent of damage to pavement markings, the quality of snow removal, and cost.

The addition of wheel supports to plows with carbide-tipped blades prolonged the retroreflectivity and service life of pavement markings. A life-cycle cost analysis revealed that carbide-tipped blades without wheels were the least expensive alternative, followed closely by carbide-tipped blades with wheels, and then urethane blades with wheels. When compared with carbide-tipped blades without wheels, carbide-tipped or urethane blades with wheels were effective in removing loose, but not packed, snow. Timely chemical application to prevent snow-pavement bonding is crucial, particularly with wheel-supported plows.

Urethane blades are susceptible to wear through friction and are impractical for use on second and third priority snow routes where variations in cross slope and soft shoulders bring the blade into contact with the pavement. The use of supports on plows equipped with carbide-tipped blades allows the operator the option to use the plow in a supported mode for first priority routes and an unsupported mode for second and third priority routes. Proper alignment of the wheels is critical to ensure proper operation, protection of the urethane blades from wear, and reduction of damage to pavement markings. Measuring the monetary value of increased and prolonged retroreflectivity of pavement markings and more effective snow removal is difficult.

The authors recommend that VDOT not use urethane blades as a replacement for carbide-tipped blades under current operating conditions. However, if VDOT continues to make brighter and more durable pavement markings a high priority, then it should consider using carbide-tipped blades on plows with wheels. Other actions that balance protecting Virginia's pavement marking investment and ensuring effective snow removal, such as restricting the use of heavy equipment for snow removal and providing operator training, should also be considered. Finally if supported plows are adopted for use, other options to support the plow should be investigated through product evaluations by VDOT personnel.

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D. S. Roosevelt
Research Scientist

B. H. Cottrell, Jr.
Senior Research Scientist

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

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INTRODUCTION

The Governor's Commission on Government Reform recommended that the Virginia Department of Transportation (VDOT) (1) evaluate urethane blades as an alternative to rubber blades, and (2) collect data concerning the damage caused by carbide-tipped blades. Two studies by the Virginia Transportation Research Council (VTRC) addressed these recommendations.[1,2] The first recommended further tests of urethane and carbide-tipped blades on wheel-supported plows.[1] Using urethane blades with high-pressure rubber tired wheels attached to the back of the plow to support its weight is standard operating procedure at airports, where this system is used extensively to protect runway lights. Urethane blades reportedly remove snow as well as carbide-tipped blades as long as no snow-pavement bond has formed. Using wheels to support the weight of the plow may reduce pavement marking damage and result in effective snow removal.

The second study found that 10 to 15 percent of pavement marking retroreflectivity was lost because of Virginia's present snow plowing technique, which uses plows with carbide-tipped blades with the full weight of the plow resting on the blade.[2] The statewide cost of pavement marking damage during the relatively mild winter of 1994-95 was about $3 million. Damage and replacement costs of this magnitude suggest that VDOT should consider ways to reduce the damage, such as using urethane and carbide-tipped blades with wheels.

PURPOSE AND SCOPE

The objective of this study was to evaluate the performance of urethane and carbide-tipped snow plow blades on wheel-supported plows. Their performance was compared with that of VDOT's standard blade arrangement: carbide-tipped blades on plows without wheels. Performance was measured by the quality of snow removal, the extent of damage to pavement markings, and cost.

METHODS

The research design of this study called for three tasks:

1. a literature review of snow plow blades and supports and their impact on pavement markings

2. an evaluation of the capability of each blade arrangement to remove snow

3. a series of before and after assessments of the impact of each blade arrangement on pavement markings.

Literature Review

The literature on snow removal activities, snow plow blades and their supports, and the impact of snow removal activities on pavement markings was reviewed. World Wide Web (WWW) sites were reviewed using Yahoo, Infoseek, Lycos, and the key words *urethane snow plow blades, snow plow wheel,* and *airport snow removal.*

Transport, a bibliographic database of transportation research information maintained by the Transportation Research Board, the Organization for Economic Cooperation and Development, and the European Conference of Ministers of Transportation, was also reviewed. The key words used were *airports, snow removal, snow plow wheels,* and *urethane.*

A literature search using TRIS was conducted in 1995. Since no documents concerning urethane snow plow blades were discovered through that search, it was not repeated for this study.

Site and Section Selection

The study method chosen involved two evaluations: one to evaluate the three types of snow plowing and another to evaluate the effect of plowing on three types of pavement markings.

The plowing evaluation required three study sections: one for urethane blades with wheels, one for carbide-tipped blades with wheels, and one control section. A *section* was defined as the portion of a route assigned to a team of snow plow operators for first priority snow removal activity.

To evaluate the effect of plowing on pavement markings, 2 sites for each of the three marking materials (waffle tape, paint, and thermoplastic) were planned for each of the three plow blade arrangements, for a total of 18 sites. One or more sites were located within each test or control section.

Study sections and sites were chosen on first priority snow removal routes, where waffle tape and thermoplastic are more likely to be used. To facilitate field review of blade performance during plowing operations, the study sections were located close to VTRC. All sections were chosen in areas where each plow arrangement could be used on second and third priority routes. Since these restrictions made it difficult to include all three types of pavement markings in each test section, additional study sections were selected, one for each plow blade arrangement, to allow an evaluation of all combinations of plow blade arrangements and pavement marking types.

Thermoplastic markings were not installed as planned at 6 sites. The 12 remaining pavement marking sites were reduced to 10 because of a series of events beyond the control of the authors. Table 1 provides descriptions of the six plowing sections. Table 2 provides descriptions of the 10 pavement marking sites. Figure 1 is a map showing the location of the study sections and sites. Table 3 describes the status of data in each section and site.

Table 1. Section Locations

Section	Route	From	To	County	Type
A	64	Albemarle Co. Line	Route 607	Fluvanna	Urethane w/ wheels
B	64	Route 607	Goochland Co. Line	Fluvanna	Carbide-tipped w/ wheels
C	64	Route 522	Henrico Co. Line	Goochland	Carbide-tipped
D	29	Nelson Co. Line	Route 692	Albemarle	Carbide-tipped w/ wheels
E	29	Route 692	Route 1106	Albemarle	Urethane w/ wheels
F	29	1106	Charlottesville City Limits	Albemarle	Carbide-tipped (Control)

Snow Plow Modifications

Urethane Blades

Urethane snow plow blades are composed of a polyurethane material, a synthetic polymer that has many formulae and can take numerous forms. The form and formula desired for this experiment were those used by airports in their snow removal operations. The specification for urethane blades used by National Airport in Washington, D.C., was reviewed, and the materials requirements were specified for the blades to be ordered. The requirements adopted are listed in Appendix A.

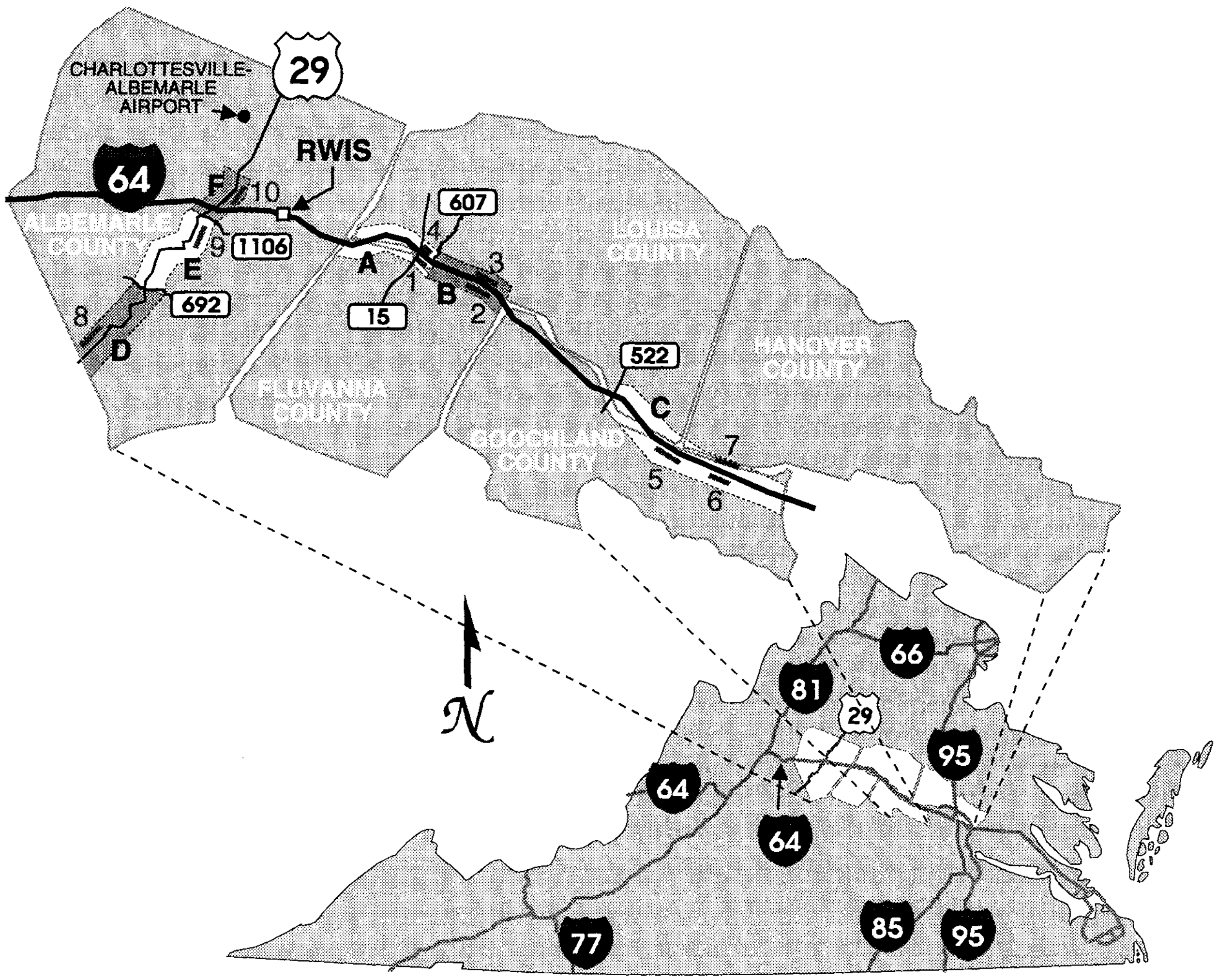


Figure 1. Location of Study Sections and Sites

Table 2. Study Sites

Site No.	Sec. No.	Direction	I-64 Sites	Length (km)	Marking Type	Plow Arrangement
1	A	EB	MP 137-MP 139	3.2	Waffle tape	Urethane w/ wheels
2	B	EB	MP 141-MP 147	9.6	Waffle tape	Carbide w/ wheels
3	B	WB	MP 141-MP 147	9.6	Waffle tape	Carbide w/ wheels
4	A	WB	MP 139-MP 137	3.2	Waffle tape	Urethane w/ wheels
5	C	EB	MP 164-MP 166	3.2	Edgelines-paint Skiplines-thermoplastic	Control
6	C	EB	MP 167-MP 168 (approximate)	2.1	Waffle tape	Control
7	C	WB	MP 167-MP 166 (approximate)	1.3	Waffle tape	Control
			Route 29 Sites			
8	D	SB	MP 4.8-P 0	7.7	Paint	Carbide w/ wheels
9	E	NB	Rt. 760-Rt. 1106	9.4	Paint	Urethane w/ wheels
10	F	NB	Rt. 1106-MP 18.8, S of Rt 250 Bus.	1.6	Paint	Control

Table 3. Status of Sections and Sites

Section	Sites	Rt/Lane	Type Plow or Marking	Status
A		64	Urethane w/ wheels	OK
	1	EB	Waffle tape	OK
	4	WB	Waffle tape	OK
B		64	Carbide-tipped w/ wheels	OK
	2	EB	Waffle tape	OK
	3	WB	Waffle tape	OK
C		64	Carbide-tipped	No data collected
	5	EB	Paint/thermoplastic	OK
	6	EB	Waffle tape	OK
	7	WB	Waffle tape	OK
D		29	Carbide-tipped w/ wheels	Dropped
	8	SB	Paint	Data contaminated
E		29	Urethane w/ wheels	OK
	9	NB	Paint	Data contaminated
F		29	Carbide-tipped (Control)	No data collected
	10	NB	Paint	OK

After discussion with urethane blade manufacturers concerning width, the size of the blades was set at 3.64 m long, 200 mm high, and 51 mm wide (12 ft long, 8 in high, and 2 in wide). This width increased the blade's rigidity and kept it from bending or folding under when it was dragged over the pavement. Each blade was fabricated with a single row of holes along the centerline of the long axis of the blade. This allowed the blade to be reversed as wear occurred on the cutting edge. A total of 12 urethane blades were purchased and were allocated 2 to a truck, with 1 additional blade available at each of the two test locations as a spare.

Steel Blades with Carbide Inserts

The carbide-tipped steel blades used on the test and control sections were standard stock blades used by VDOT throughout Virginia. The blades were S.A.E. 1020 or 1031 steel, with tungsten-carbide inserts. The requirements for the carbide tips are listed in Appendix A. Since these were a stock item, no special order was made. The area headquarters' staff drew the blades from stock as needed.

Castor Wheels

The snow plows assigned to the four test sections were modified to add castor wheels to support the frame. Castor wheel assemblies were purchased for the 10 plows assigned to the four test sections and attached to the plow frame in accordance with the manufacturer's recommendations.

The option of using larger rubber tired wheels was investigated but found to be infeasible. Many airports use these wheels on their plows. Airport snow plows and trucks, however, are larger and have more room between the truck and the plow to accommodate the larger diameter rubber tired wheel. After discussions with a number of snow plow manufacturers, it was determined that rubber tires could not be used unless larger snow plow frames were also used. Since the discarding of VDOT's existing plowing equipment was not an option, modifications were limited to options available for existing equipment.

Evaluation of Snow Plowing

Snow plowing was evaluated for quality of snow and ice removal, the effort involved in its removal, and the cost of such removal. This evaluation was made by comparing snow removal on the test sections and control section during winter storms. Information gathered during each storm for comparison was as follows:

- weather conditions
- snow removal activity
- pavement conditions
- blade and plow maintenance.

Weather Conditions

The weather conditions during each storm were obtained through three sources. Local area daily precipitation and hourly air temperatures over the life of the storm were provided by the State Climatologist's office. The air temperature information was supplemented by a road weather information system (RWIS) station owned by VDOT on Route 64 at the Rivanna River Bridge. This station also supplied pavement temperatures and confirmation of precipitation on an intermittent basis during each storm. Logs kept by the operators provided information on the type of precipitation occurring on each section during each storm.

Snow Removal Activity

A log of the action taken to control and remove snow and ice during each storm was kept by each operator. Each entry indicated the type of activity and the type of material and rate of application if applicable. The location by lane of the activity was also designated. The field activity log sheet, or operator input form, is shown in Appendix B.

Pavement Condition

Pavement condition was logged by operators during snow removal operations. Operators judged the condition of the wheel track area and the area outside the wheel tracks and assigned it one of seven defined conditions. Observations were recorded on the log sheet shown in Appendix B.

Blade and Plow Operation and Maintenance

The operators were interviewed after each storm. Actions that affected the operation and maintenance of the plow, the schedule, or the cost of the plowing operation were recorded.

Pavement Marking Data Collection and Analysis

Drive throughs of the test sites were performed by the study team to assess the condition of pavement markings. Portions of selected test sites were selected for more in-depth assessment, including a shadow test and retroreflectometer readings.

Shadow Tests

Shadow tests were conducted by an observer positioned with the sun behind him and the shadow of his head on the pavement marking being observed. From this position, the observer could determine if retroreflectivity was uniform across and along the marking. This test is particularly useful in determining if beads were uniformly applied during installation and in identifying spots where beads were scraped from the marking. Shadow tests were performed before, during, and after the snow season and when the retroreflectivity readings were taken. The pavement was dry during this test.

Retroreflectivity Measurements and Analysis

Retroreflectometer measurements were recorded to assess the nighttime visibility of the markings, and closeup observations determined the condition of the markings. A minimum of 18 measurements were recorded for each site. Six each were recorded in the beginning, middle, and end of the study section. For the one site that was 9.6 km (6 mi) long, 6 measurements were taken at each of five locations at 1.6-km (1-mi) increments. Data were collected three times: before, during (after 1), and at the end of the snow season (after 2).

The three sets of data were compared to determine the change in retroreflectivity and extent of damage to pavement markings. The mean retroreflectivity measurement and its standard deviation were calculated for each site. The percent of retroreflectivity loss and the amount of markings damaged were the primary measures of performance. The differences between the before and during and the before and after measurements were compared for the three plow arrangements. Sites with similar pavement markings and plow treatment were combined to increase the number of samples (measurements) and the power of the test. First, the data, percent of retroreflectivity loss, were reviewed to determine if the sites to be combined performed similarly. The z test for comparing proportions was then used to determine if the differences in the percent of retroreflectivity losses for the different plow arrangements were significant. The cost of the damaged pavement markings and retroreflectivity loss was estimated.

RESULTS

Literature Review

A search of the WWW using Yahoo, Infoseek, and Lycos and the key words *urethane snow plow blades* failed to turn up any information on snow removal with urethane blades. A search of the phrase *snow plow wheels* produced no information. A search using *airports and snow removal* produced three sites. One was a press release, and the other two were FAA policy statements that did not discuss snow plow procedures or blades in detail.

The search of the Transport database on CD ROM, current through February 1996, revealed seven studies completed since 1988 that matched the key words *airports and snow removal*. When the key word *urethane* was added, there was only one response. This match was the previous study of urethane blades done by the authors. The other six studies referred to materials research or magazine articles on plowing that gave no detail on snow plow blades. The phrase *snow plow wheels* produced no information.

Evaluation of Snow Removal

Weather

Road conditions during three snow storms in 1996 were studied. The storms covered the following dates:

Storm 1	January 6-8
Storm 2	January 12
Storm 3	February 2-3

Information on the weather conditions for each storm is provided in Appendix C.

Snow Removal Activity

Snow removal activity was recorded for each plow operating in five of the six sections. This information covered the activity for 11 trucks during each storm. Information on the activity of each truck is provided in Appendix D. Only the data collected in Sections A and B were suitable for analysis.

The data for 6 trucks operating in Sections A and B were collected during each storm. The three storms were divided into eleven 12-hour periods, with the 8 o'clock shift change being the break point between periods:

Date	Time Period
1/6	8A-8P
1/6-7	8P-8A
1/7	8A-8P
1/7-8	8P-8A
1/8	8A-8P
1/11-12	8P-8A
1/12	8A-8P
2/2	12M-8A
2/2	8A-8P
2/2-3	8P-8A
2/3	8A-8P

Pavement Conditions

Only the data collected for Sections A and B were suitable for comparison.

Comparison of Operations in Sections A and B

The data on precipitation, temperature, snow removal activity (vehicle activity, materials used, and lane location), and resulting pavement condition were compared for Sections A and B for each of the three storms. The vehicle activity and pavement condition data are shown in Appendix E.

Storm 1

For Storm 1, precipitation began about noon on January 6. The trucks on Section A equipped with urethane blades with wheels maintained bare pavement throughout the first 18 hours, whereas the trucks on Section B equipped with carbide-tipped blades with wheels had packed snow on the pavement after the first 6 hours. The use of salt in Section A between the fourth and sixth hour kept a snow-pavement bond from forming. The crew in Section B did not apply chemicals.

From 4 P.M. to 6 P.M., the air temperature was -6 °C (22 °F) and the pavement temperature was -4 °C (25 °F), temperatures at which sodium chloride would have created a good bond-breaking brine relatively quickly. The air temperature dropped to around -9 °C (15 °F) overnight, which would have led to a snow-pavement bond on the untreated section but would have allowed the brine on Section A to continue working and the snow on the treated section to be removed. By midday on January 7, the effect of the chemicals on Section A was neutralized and a snow-pavement bond had formed. Temperatures remained in the low 20s. On the night of January 7, neither section used chemicals and temperatures stayed in the low 20s. Once the snow-pavement bond had formed, neither plow arrangement or type of plow blade could cut through the packed snow at these temperatures.

The data supported the widely held opinion that breaking the snow-pavement bond is the single most important factor in maintaining bare pavement. Sufficient application of chemicals at the proper time allowed the urethane blades to remove snow during the first 18 hours. The carbide-tipped blades with wheels did not remove the packed snow even though the section was plowed eight times in the travel lane and six times in the passing lane during the 12 hours from 8 P.M. on January 6 to 8 A.M. on January 7. The pavement condition data for Section A for the early morning hours of January 8 were contradictory in that alternating reports indicate loose and packed snow, but later reports indicate that packed snow remained on both sections until after the temperature rose to near 0 °C (32 °F) around 2 P.M.

Storm 2

Storm 2 began just after midnight on January 12. Snow plows in Section A equipped with urethane blades with wheels kept the pavement bare in both lanes throughout the storm whereas Section B had packed snow on at least one lane during the first 12 hours. Again, chemical use rather than plow arrangement was the reason for this difference. Use of salt on Section A in the travel and passing lanes kept a bond from forming on either lane. On Section B, salt was placed in the passing lane only. Air and pavement temperatures around -6 °C (21 °F) at the time of application would have inhibited brine formation, and placement of salt in both lanes improved the chances of full coverage. The snow stopped after 10 A.M., and the air temperature after 1 P.M. on January 12 was above freezing. Neither factor seemed to help the plows on Section B cut the snow-pavement bond, but the brine on Section A allowed the plows to remove the snow accumulated on the pavement.

Storm 3

Storm 3 began just after midnight on February 2. Plows on Section A kept both lanes clear through most of the first 24 hours. On Section B, snow was packed on the passing lane throughout most of the storm. Again, the timing of chemical application appeared to be the most important factor in keeping the pavement clear. Plows on Section A placed salt at a rate of 66 kg/lane km (250 lb/lane mi) in the first hour. Although the air temperature was around -6 °C (21 °F) at that time, the pavement surface temperature was -4 °C (25°F), which would have allowed a good brine to form. When plows on Section B applied salt 2.5 hours into the storm, the passing lane already had packed snow. The salt brine bond breaker on Section A allowed the operators to keep the pavement clear with plowing alone for 24 hours. Although reports on the condition of the through and passing lanes were contradictory, operators on Section B had problems clearing snow with the carbide-tipped wheel-supported plows because a bond had already formed.

Although no data were collected for the control section, observations of operators and researchers were collected on the comparative quality of snow removal. The consensus was that if no snow-pavement bond is formed, wheel-supported plows will remove snow as well as non-wheel-supported plows. If snow-pavement bonding occurs, however, wheel-supported plows tend to ride on top of the snow and will not cut into packed snow. At the temperature ranges during these storms, -9 to -6 °C (15 to 20 °F), the ability of non-wheel supported plows to cut snow off pavement once a bond had formed was limited. The noticeable difference in performance between wheel-supported and non-wheel-supported plows occurred when temperatures were near freezing. In those situations, non-wheel-supported plows cut the packed snow off the pavement whereas the wheel-supported plows rode over the surface of the snow. The comments of the operators interviewed are provided in Appendix F.

Blade and Plow Operation and Maintenance

There were a number of problems associated with installing the blades and wheels on the wheel-supported plows and operating the plows during the storms. These findings were based on the authors' experience and interviews with the operators.

Most VDOT snow plows are reversible; that is, the plow moldboard can be shifted to discharge snow to the left, to the right, or straight ahead. As shown in Figures 2 and 3, to facilitate this movement, the plow moldboard and circle are attached to the subframe at a single point *(pin)* and rotate around this point *(axis of rotation).* A notched semicircle *(the circle)* rigidly attached to the back of the moldboard, and in contact with a spring-loaded key on the subframe, holds the moldboard at the desired angle. This arrangement allows the moldboard to rotate slightly, or rock, around an axis coincident with the direction of travel of the vehicle. When the blade rides on the surface of the road, this ability to rock allows the blade to follow the cross slope of the road surface. Installing wheels changes this arrangement. The moldboard still rocks, but the wheels become the intended point of contact with the road.

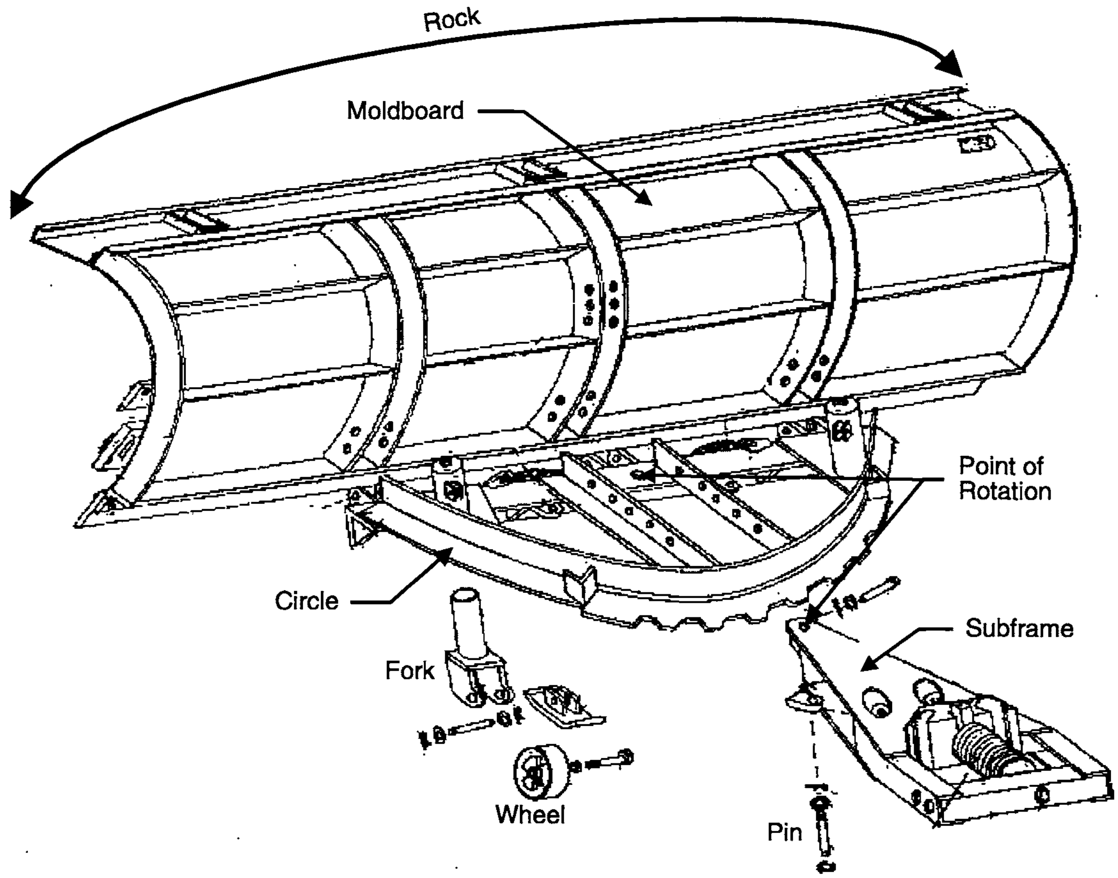
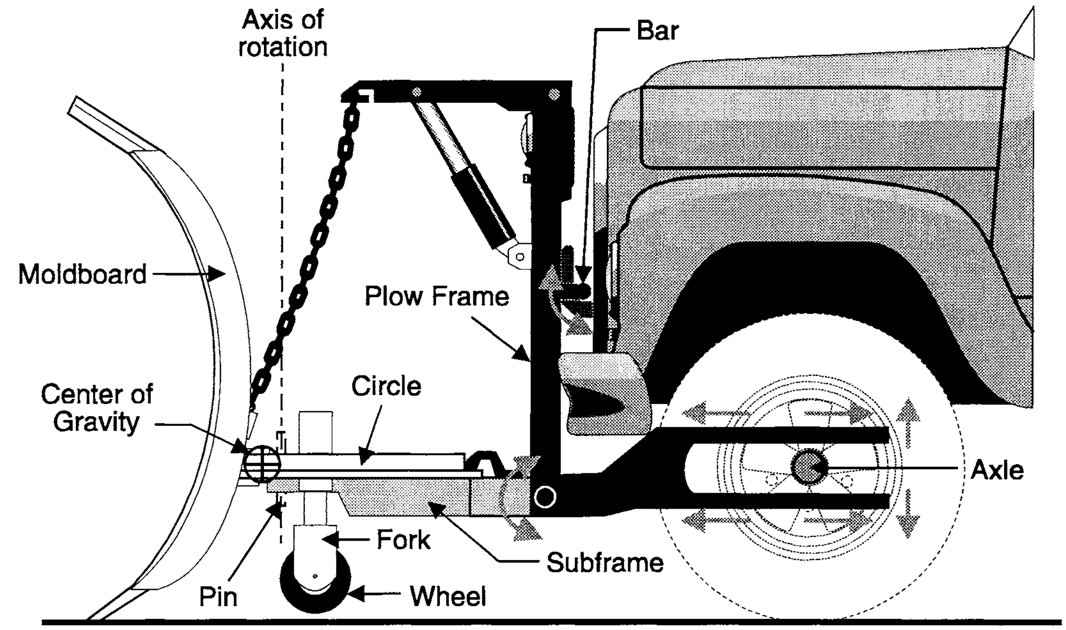


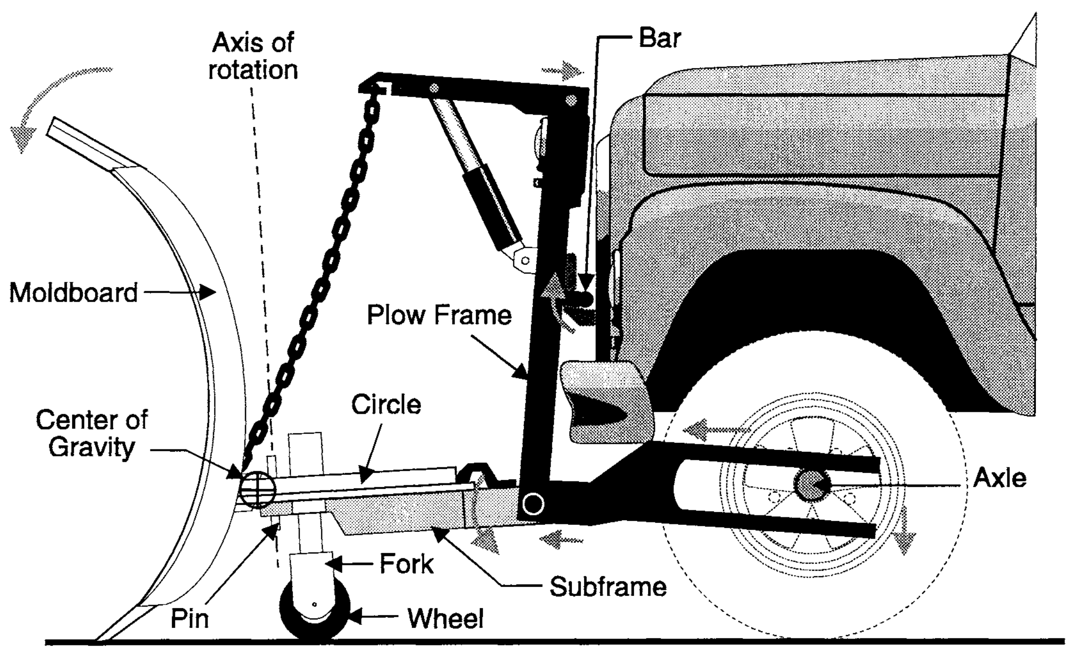
Figure 2. Plow Moldboard and Frame

The wheels were installed on the circle in accordance with the manufacturer's recommendations. The wheels are located nearer the axis of rotation than the ends of the blade. Therefore, it is important that the axis of rotation be perpendicular to the road surface so that the circle will rotate in a plane parallel with the road surface. Adjusting the subframe and the circle to be parallel with the road surface is defined here as *leveling.*

Leveling the subframe and circle proved to be difficult. The plow frame is not rigidly attached to the truck (Figure 3). It is firmly attached to the truck by a bar that allows it to rotate slightly, but freely, around a horizontal axis perpendicular to the direction of travel. The subframe, in turn, rotates freely around its connection to the plow frame. The center of gravity of the subframe and plow is in front of the wheels attached to the circle. The result is that as the wheels are lowered to the road to take the weight off the plow blade, the plow rotates forward, maintaining contact with the road surface until the plow frame's rotation is halted. Only then



Plow orientation with wheels raised



Plow orientation with wheels lowered

Figure 3. Schematic of Plow and Frame

does the plow rise as the wheels are lowered. This forward rotation of the plow causes the axis of rotation to tilt forward. The result is that for any given angle of the moldboard, the wheels can be adjusted to hold the blade above the road surface. Changing the angle of discharge of the moldboard, however, will raise one end of the blade and lower the other end. This action resulted in one end of the blade rubbing on the road surface. The circle and subframe could not be leveled on any of the 10 trucks and plows equipped with wheels without modification of the permanent connections between the plow frame and the truck.

The wheel assemblies are welded to the circle parallel with the axis of rotation. As the circle tilts forward, the long axis of the fork tilts forward and away from a true vertical. This affects the alignment of the wheels and causes them to drag when the plow is in motion. The result was that the castor wheels on most of the plows showed wear. The wear was so extreme on 2 plows that the wheels were replaced between the second and third storm. The 2 trucks on which these plows were installed also displayed handling problems. The drag of the castor wheels was so great that when the operator would make a 90° turn in the direction the moldboard discharged, the effect was to push the truck in that direction. Two operators described the sensation as "being thrown into the bank."

Adjusting the height of the wheels was physically difficult. The wheels are adjusted up and down with a screw jack. The weight of the plow and the friction between the screw and housing made turning the screw difficult. In many cases, an extension had to be added to the handle to allow one person to turn it.

In all sections monitored, the blade angle was changed as part of normal operations during every storm. The carbide-tipped blades with wheels were not affected by this operation, but the urethane blades were susceptible to rapid wear whenever they were in contact with the road surface. All 5 of the original blades were turned over to allow use of the second side by the end of the winter, and 3 of the original blades were replaced. Two replacement blades had been turned over, meaning the blade had effectively been replaced three times during the winter. None of the carbide-tipped blades, either wheel supported or in the control section, was replaced.

Pavement Marking Evaluation

The shadow test and visual inspection results cover all 10 study sites. For retroreflectivity results, readings are briefly discussed for the sites with paint and/or thermoplastic markings. The 6 sites studied on Route 64 included 2 waffle tape sites for each of the three snow plow configurations. Because the waffle tape was the only marking exposed to all three snow plow configurations for the duration of the study, the focus of the evaluation was on the waffle tape sites.

Shadow Tests

As expected, before the first snow plowing, all markings were in very good to excellent condition. At the end of the snow season, some markings were damaged (see Table 4). On Sites 1 and 4 (urethane blades with wheels and waffle tape), some beads were scraped off. Most scraped sections covered less than 30 percent of the cross section of the marking. Occasionally, these sections appeared as periodic, almost cyclic, spots. Although they were minor and had a spotty or patchy look, they were visible throughout the test sections. The white edgelines incurred the most scraping. Along Sites 2 and 3 (carbide-tipped blades with wheels and waffle tape), slightly more scraping occurred than at Sites 1 and 4. Sites 6 and 7 (control and waffle tape) clearly showed the most scraping. On Site 6, the entire section of white edgelines (about 25 km [80 ft]) at one location showed substantial, continuous scraping along the inside edge of the line nearest the travel lane. On Site 7, one section appeared to be missing about 50 percent of the beads on the white edgelines. Along Sites 6 and 7, the yellow edgelines also showed evidence of scraping, especially toward the inside at Site 6. At Site 5, where control blades were used, the thermoplastic skiplines appeared to be in very good condition. Although some scrape marks were observed along the outside edge of the white paint edgelines, the painted edgelines looked good.

The white edgelines along Sites 9 (urethane blades and paint) and 10 (control and paint), especially Site 10, appeared almost bare of beads.

Table 4. Shadow Test Results After Snow Season

Sites	Marking	Blade	Condition
1 and 4	Waffle tape	Urethane	Very good
2 and 3	Waffle tape	Carbide	Very good
6 and 7	Waffle tape	Control	Good to poor
5	Thermoplastic-skiplines Paint-edgelines	Control	Thermoplastic-very good Paint-good
9	Paint	Urethane (loader and control used on edgelines once)	Poor
10	Paint	Control	Poor

Visual Inspections

Visual inspections revealed some sections with a line or trail of rust-colored marks. This was most noticeable on the white edgelines in sites where wheels were used. According to operators, it is likely that the wheels "locked" and dragged instead of rolled during plowing. These trails were also observed on the pavement, especially in the right lane, and on skiplines, yellow edgelines, the left lane, and the right shoulder. Tears and chips in the tape were observed in isolated sections, but the extent of the damage was not enough to require replacement. Most noticeably, small chunks were missing on the white edgelines at Site 7 (control and waffle tape). No pavement markings required replacement.

Retroreflectivity

Figure 4 displays the retroreflectivity readings for the three markings at Site 5 (control and thermoplastic and paint). The thermoplastic skiplines and white paint edgelines lost the same percent of retroreflectivity from before to after 1 (first to second reading). From after 1 to after 2 (second to third reading), the white paint edgelines lost about the same percent of retroreflectivity as from before to after 1, whereas the thermoplastic skiplines show a slight increase in retroreflectivity. The accuracy of the retroreflectometer is ±4 percent; the slight increase is within this range. The readings for the yellow edgelines were low for all three time periods but increased 6 percent. The low readings were probably due to the yellow edgelines being more than 1 year old. Also, based on the experience with this type of retroreflectometer of VDOT staff and others, it is suspected that the retroreflectometer is less accurate at lower retroreflectivity levels. Therefore, the 6 percent increase is suspect.

Figure 5 shows the changes in retroreflectivity of the white and yellow edgelines on Sites 9 (urethane blades with wheels and paint; loader and carbide-tipped blades used on shoulders once) and 10 (control and paint). These sites had the largest reduction in retroreflectivity.

Findings for Sites 1 and 4 (urethane blades with wheels and waffle tape), 2 and 3 (carbide-tipped blades with wheels and waffle tape), and 6 and 7 (control and waffle tape) were combined. All further analyses for these sites were for the combined sites. Figures 6 through 8 show the changes in the retroreflectivity measurements of the three conditions for the skiplines, white edgelines, and yellow edgelines, respectively. As expected, retroreflectivity decreased after the first set of readings in most cases. Unexpectedly, many readings increased from the second to third set. There are two possible explanations for this. First, most of the increases fell within the level of accuracy of the retroreflectometer. Second, several rainstorms that occurred before the third set of readings cleaned the markings. Members of the study team observed a visible improvement in the markings at some sites: they looked cleaner. A combination of these two factors is also possible. Figure 6 shows that the retroreflectivity of the skiplines where carbide-tipped blades with wheels were used changed only slightly. The skiplines and white edgelines at the control sites had the largest loss in retroreflectivity from the first to the second readings, as shown in Figures 6 and 7. Figure 7 reveals that the white edgelines where the urethane blades with wheels were used had the least loss in retroreflectivity. Figure 8 shows that retroreflectivity changed least on the yellow edgelines among the different blade types.

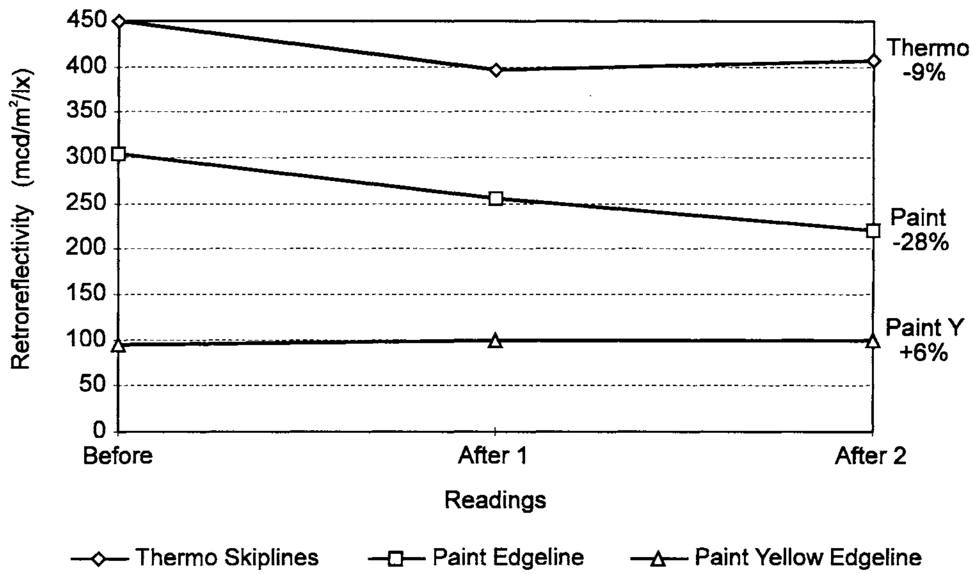


Figure 4. Site 5 (Paint vs. Thermoplastic)

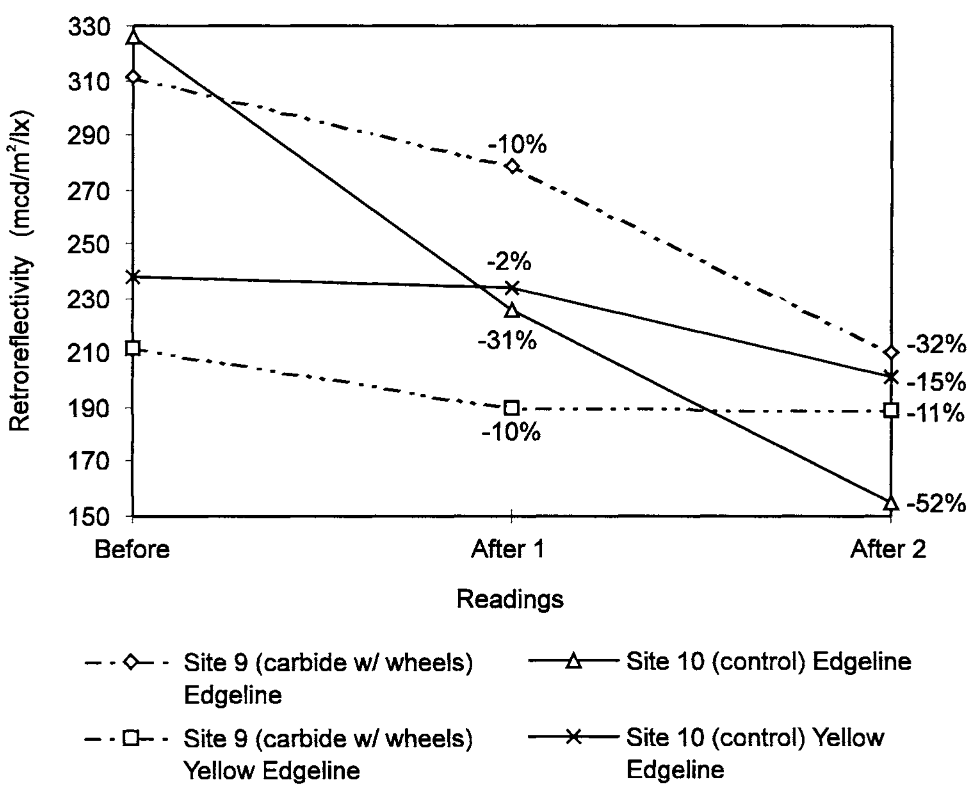


Figure 5. Site 9 (Carbide with Wheels) and Site 10 (Control)

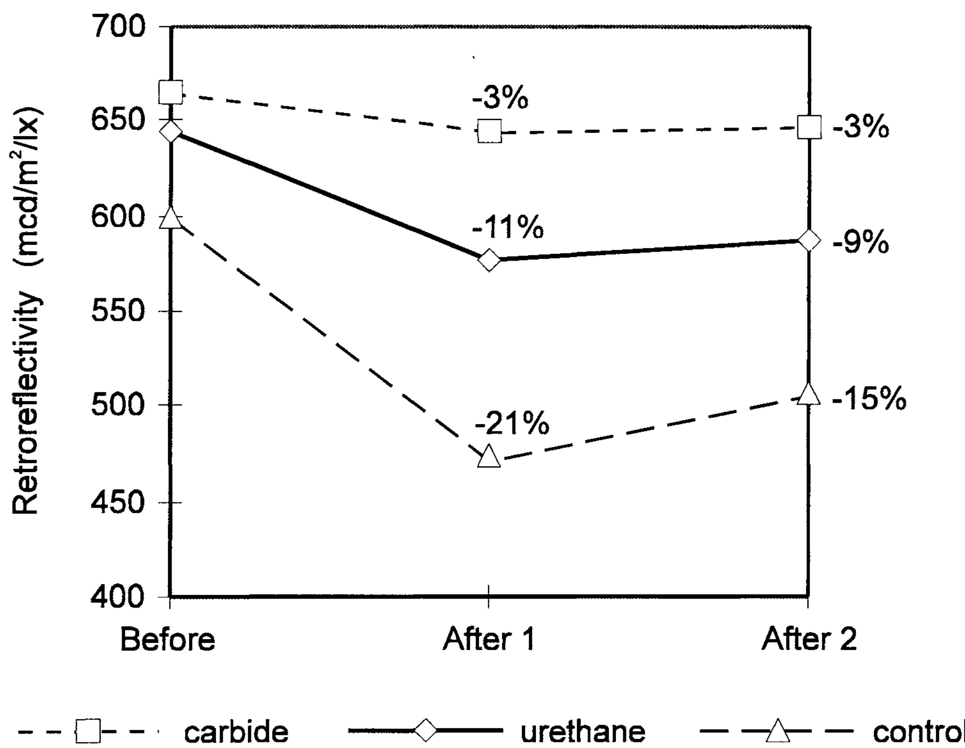


Figure 6. Retroreflectivity of Waffle Tape Skiplines

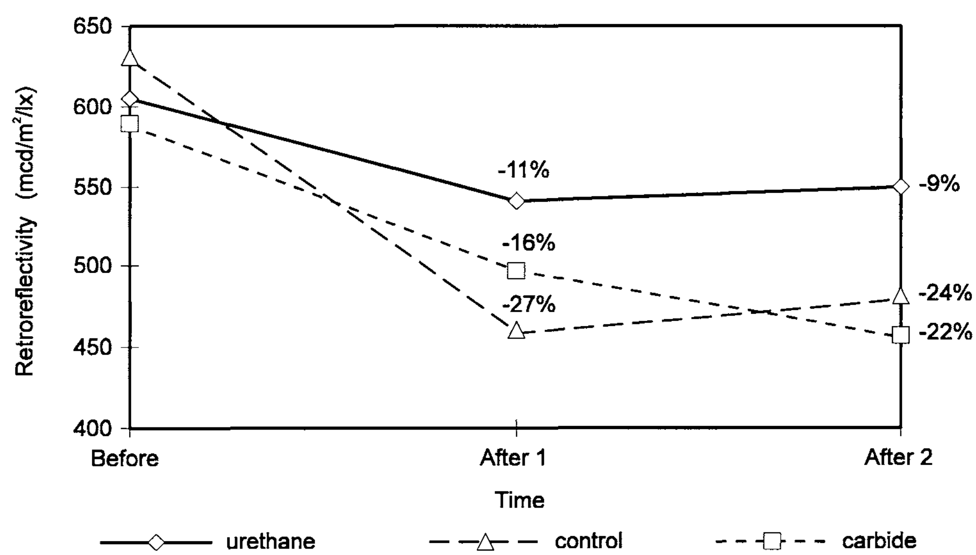


Figure 7. Retroreflectivity of Waffle Tape Edgelines

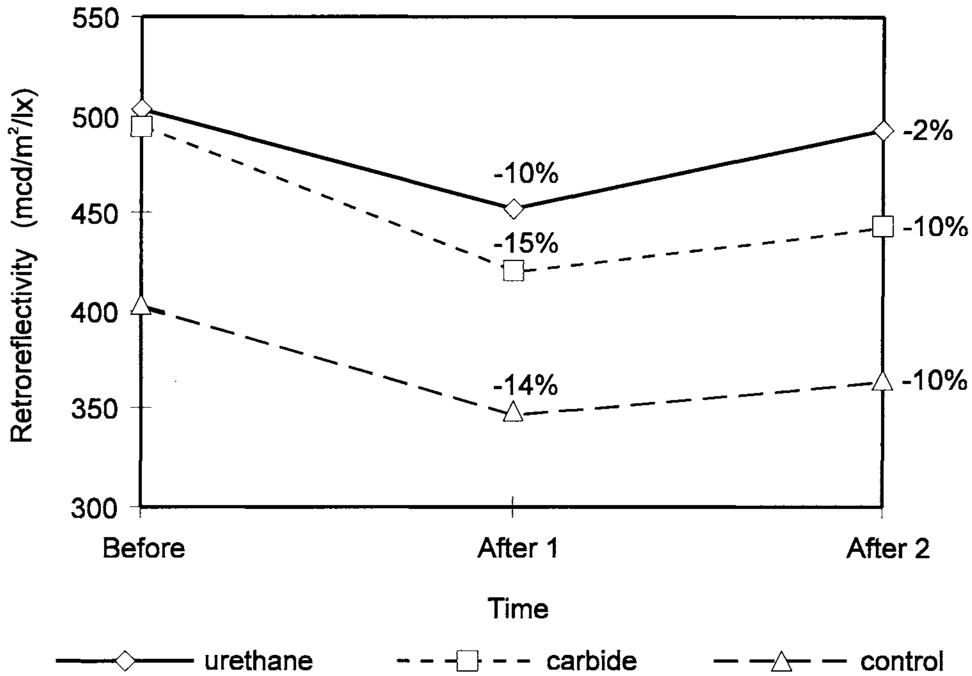


Figure 8. Retroreflectivity of Waffle Tape Yellow Edgelines

Statistical Tests for Comparing Proportions

Table 5 shows the results of a one-tailed z test for determining if the percent change in retroreflectivity of one plow treatment is significantly different from the other treatments at a 95 percent confidence level.[4] The percent loss in retroreflectivity for the skiplines, white edgelines, and yellow edgelines were averaged to yield a percent loss for all markings for each blade type. The tests were done on the difference between the first and second readings and the first and third readings. When compared to the control treatment, retroreflectivity decreased significantly less from the first to the second readings for the two blades with wheels. Only with the urethane blade treatment did retroreflectivity decrease from the first to the third readings. Between the urethane and carbide-tipped blades with wheels, the difference was significant only between the first and third readings. Use of the urethane blade resulted in the least retroreflectivity loss.

Estimated Annual Value of Retroreflectivity Loss

Table 6 shows the results of the value analysis based on the loss of retroreflectivity. The expected percent loss of 6 percent without snow plowing was based on the findings of a previous study by one of the authors.[2] Using this figure permitted the calculation of an estimated annual percentage loss in retroreflectivity of pavement markings based solely on snow removal activities. The value of this loss was based on the same percentage of the initial cost. In other words, a 10 percent loss in retroreflectivity equals a 10 percent loss in value of the marking. The value was measured per kilometer (mile) for one direction of a four-lane divided highway. The

Table 5. Results of Statistical Tests

	All Markings		Compare with Control		Compare Urethane and Carbide		% Less Damage Than Control		% Less Damage Than Carbide	
	% Diff 1-2	**% Diff 1-3**	z_{1-2}	z_{1-3}	z_{1-2}	z_{1-3}	**% Diff 1-2**	**% Diff 1-3**	**% Diff 1-2**	**% Diff 1-3**
Urethane	-10	-7	3.11*	3.79*	0.38	2.69*	11	9	1	5
Carbide	-11	-12	3.08*	1.45			10	4		
Control	-21	-16								

One-tailed test $z_{0.05} = 1.65$.
*Significantly different.

Table 6. Estimates of Annual Value of Retroreflectivity Loss by Plow Arrangement

	Urethane	Carbide	Control
% total retroreflectivity loss	7	12	16
% expected retroreflectivity loss	6	6	6
% retroreflectivity loss by plow configuration	1	6	10
Initial marking cost ($/km)	12,994	12,994	12,994
Initial marking cost ($/mi)	20,790	20,790	20,790
Value of retroreflectivity loss ($/km)	130	780	1,299
Value of retroreflectivity loss ($/mi)	208	1,247	2,079
Value savings over control ($/km)	1,169	520	
Value savings over control ($/mi)	1,871	832	
Value savings over carbide ($/km)	650		
Value savings over carbide ($/mi)	1,040		

estimated annual value per kilometer for retroreflectivity loss was $130, $780, and $1,300 for urethane blades with wheels, carbide-tipped blades with wheels, and control, respectively. (The value per mile for retroreflectivity loss was $210, $1,250, and $2,080 for the urethane blades with wheels, carbide-tipped blades with wheels, and control, respectively.) If urethane blades were used in lieu of the control, the annual savings in reduced retroreflectivity loss would be $1,170 per km ($1,870 per mi). Similarly, if carbide-tipped blades with wheels were used in lieu of the control, the annual savings in reduced retroreflectivity loss would be $520 per km ($832 per mi). Based solely on the impact on pavement marking retroreflectivity, the urethane blade with wheels would provide the least loss in retroreflectivity and retain the highest value of the pavement marking. From the perspective of protecting the investment in pavement markings, the preferred plow treatments would be ranked as urethane blade with wheels, carbide-tipped blade with wheels, and the control.

Comparison with Other Markings

Figure 9 illustrates how the retroreflectivity of the tape varied by plow treatment over the service life of the marking. Since data were collected over only one winter for this study, the relationship between retroreflectivity and service life was assumed to be linear. Retroreflectivity data collected on 2- and 4-year-old waffle tape supported the linear relationship for the control.[3,5] New thermoplastic and paint markings were used as a reference point for comparison. The waffle tape remains brighter than new thermoplastic for about 2 ½ years for the control, about 3 ½ years for carbide-tipped blades with wheels, and about 5 2/3 years for urethane blades with wheels. Similarly, the waffle tape remains brighter than new paint for about 4 1/3 years when the control is used, about 5 3/4 years for carbide-tipped blades with wheels, and the life of the pavement for the urethane blades with wheels. One of the reasons for using waffle tape is to provide the brightest (or highest retroreflectivity) and most durable pavement markings available on higher class, or limited access, highways.

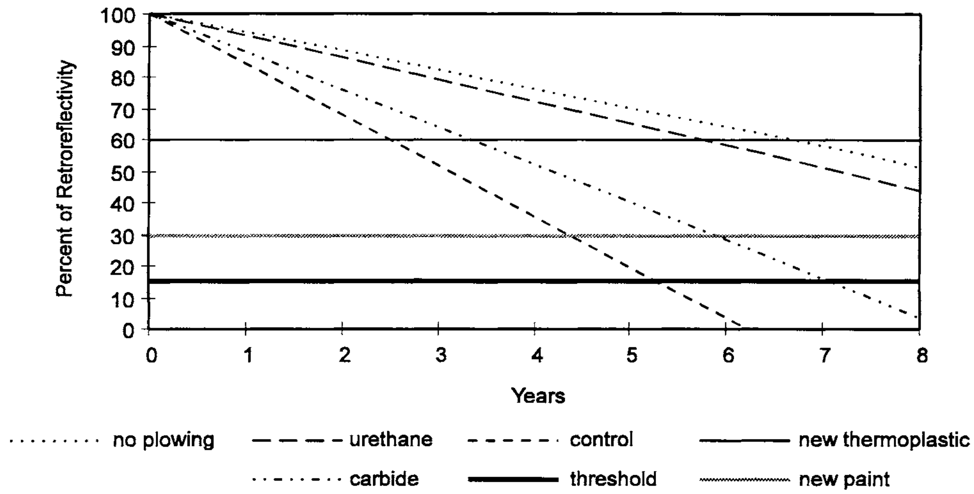


Figure 9. Service Life of Waffle Tape by Blade Type

Estimated Impact on Service Life of Markings

The manufacturer of the waffle tape, 3M, provides a 6-year warranty that covers replacement of the tape based on its failure to adhere to the roadway or maintain a minimum retroreflectivity level. The actual costs to VDOT are based on the initial costs of the waffle tape markings and any marking replacement costs incurred after the 6-year warranty expires and before the pavement is resurfaced.

The method used to estimate the service life of the markings based on snow plowing with the three blade configurations was as follows: It was assumed that the markings require replacement when retroreflectivity reaches 100 mcd/m^2/lx because the warranty requires replacement when retroreflectivity is below this level. This is about 15 percent of the initial value for white waffle tape. The service life was estimated based on the time it would take waffle tape to reach 15 percent of its initial retroreflectivity value using the percentage loss in retroreflectivity shown by the three blade configurations and a no plowing loss rate of 6 percent.

The estimates of service life are shown in Table 7 and Figure 9. Although the marking service life for urethane blades with wheels and no plowing is 12.1 and 14.2 years, respectively, the actual service life of the markings is limited by the expected pavement life of 8 years based on historical data.[6] It is estimated that use of the control plow will result in a service life of 5.3 years. Under the warranty, the markings would be replaced, probably with a liquid marking, to provide the minimum retroreflectivity for the remainder of the 6-year warranty. After the warranty expires, VDOT would assume the cost for marking replacement. Given the pavement life of 8 years, it is likely that paint would be used to replace the tape.

Table 7. Estimated Marking Service Life by Plow Arrangement

Plow Type	% Retroreflectivity Loss/Year	Estimated Service Life (yr)
No plowing	6	14.2
Urethane	7	12.1
Carbide	12	7.1
Control	16	5.3
Warranty		6
Pavement life		8

Costs

Estimated Annual Cost of Snow Plows and Blades

Ten plows at four locations were modified for this study. Twelve urethane blades were purchased for use on 5 of those plows. The wheels were purchased from the plow manufacturer to ensure proper fit and operation. Since the wheels were purchased separately, the cost was higher than if the plows had been purchased with wheels. This higher cost is used throughout the cost estimate and comparison since wide scale implementation of this method of plowing would be feasible only if existing equipment were modified.

Since the majority of plows used by VDOT are manufactured by Valk Manufacturing, their wheel assembly costs were used. The blade costs are based on carbide-tipped blades lasting a full winter season and urethane blades being replaced only once during a winter season. The estimated cost per season per plow is shown in Table 8.

Table 8. Estimated Cost per Season per Plow

Item	Normal	Carbide w/wheels	Urethane w/wheels
Wheel assembly	---	$900	$900
Initial blade	$125	$125	$650
Replacement blade	---	---	$650
Labor to replace blade	---	---	$25
Total	$125	$1025	$2825
Increase over normal snow plowing	0	$900	$2700

The prices shown are for the limited quantity purchased. A bulk purchase price is also shown for the Valk Manufacturing units, since it was used in the life-cycle cost analysis. Only materials costs are shown.

Castor wheel assembly, housing, and hardware:

American Road Machinery with 250 mm (10 in) wheels	$640.00 ea.
Valk Manufacturing with 200 mm (8 in) wheels	$762.50 ea.
(Bulk purchase)	($450.00 ea.)

Snow plow blades:

Urethane	$650.00 ea.
Carbide-tipped	$125.00 ea.

Life-Cycle Cost Analysis

This analysis compared only the benefits of extended pavement marking life versus the increased cost for snow plowing derived from using carbide-tipped or urethane blades. The comparison is based on the costs and benefits accruing to a 1.6-km (1-mi), two-lane-wide section of road, which is one side of a four-lane divided highway. The analysis assumed the following:

1. Each plow is assigned 9.6 km (6 mi) of two-lane roadway, and each 1.6 km (1 mi) absorbs 1/6 of the modified plow costs.
2. Wheels are replaced each year.
3. A carbide-tipped blade is used for one full winter season.
4. Urethane blades are replaced once each winter season.
5. Tape markings are replaced when retroreflectivity drops below 100 mcd/m^2/lx.
6. Tape markings are replaced with paint.
7. VDOT is responsible for the replacement cost of tape only after the sixth year.
8. The average life of the pavement is 8 years.
9. There is no discount factor.

The analysis shown in Table 9 annualizes all costs over an 8-year period and reveals the following: (1) plow modifications represent the majority of the cost differences among the three plow configurations; (2) carbide-tipped blades with wheels cost $139, or about 5.5 percent more than the control or normal practice; and (3) urethane blades with wheels cost $428, or about 16.3 percent more than the normal practice. The added costs of wheels would be further reduced over time as new plows were purchased with wheels.

Table 9. Annualized Cost of Plow Configurations

	Type of Blade		
Annual cost of:	**Normal Practice**	**Carbide-Tipped w/ Wheels**	**Urethane w/ Wheels**
Life of pavement markings	5 years	7 years	8 years
Tape pavement marking	$2600	$2600	$2600
Plow modifications	$0	$150	$450
Marking replacement	$22*	$11	0
Total	$2622	$2761	$3050
Difference from normal practice	0	+$139	+$428
% difference from normal practice	0	+5.5	+16.3

*Excludes $90 cost to 3M Company to paint lines in sixth year under warranty.

DISCUSSION

Snow Removal

Quality of Snow Removal

Observations of plowing with wheel-supported urethane blades by one of the authors and plow operators supported the comments by a urethane blade manufacturer and airport maintenance personnel. Where no snow-pavement bond has formed, urethane blades remove snow as well as non-wheel-supported carbide-tipped blades. If a bond has formed, the snow removal performance of urethane blades is considerably less than that of carbide-tipped blades. Supporting carbide-tipped blades with wheels reduces their ability to cut into the snow and makes them no more effective than urethane blades. This being the case, using wheel-supported plows should be considered only where chemical applications are used (first priority snow routes).

Snow Plow and Blade Installation and Operation

The problems with installation and operation noted previously should be tempered with the fact that the crews were unfamiliar with both urethane blades and wheel-supported plows. The problem with wheel wear occurred because the wheels were not aligned properly. Proper alignment requires additional effort and training that were infeasible in this study because of the time constraint and focus. If a large number of VDOT's existing plows were to be modified, technical assistance from the plow manufacturers would probably resolve the problem quickly.

Proper wheel alignment would better protect the urethane blade from coming in contact with the pavement. If used on relatively smooth pavements, urethane blades on properly aligned wheel-supported plows can be expected to last longer than the urethane blades used in this study. In most maintenance areas, however, all snow plows are assigned to first, second, and third priority routes. The relatively rough vertical alignments and cross sections on second and third priority routes will cause rapid wear of urethane blades. Additionally, the sporadic use of chemicals on second and third priority routes resulting in a prevalent snow-pavement bond suggests that urethane blades be used only on first priority routes. Under the current operating procedure, such use would require additional plows for second and third priority routes.

Proper alignment of the supports should improve the ability of an operator to adjust the supports up or down on the plow. If carbide-tipped blades are used, the supports could be raised to allow plowing using the standard operating procedure on second and third priority routes.

Pavement Markings

Warranty Costs

About 5 percent of the installation cost of waffle tape is intended to serve as warranty cost coverage. For the last two winters, about 10 percent of the waffle tape installed during the previous construction season was replaced under warranty at a cost of about $800,000 per year statewide. After the winter of 1994-95, the major reason for replacement was that tape overlay installations were more likely to fail because of poor adhesion. That year, VDOT changed its practice to require inlay installation: installation on asphalt pavement overlays within 2 to 3 days of the overlay. The major reason for tape replacement in the winter of 1995-96 appeared to be late season application. Installations made after September 15 appeared to be susceptible to snow plow damage because of poor adhesion. The installation appeared to be temperature sensitive. Most of this replacement occurred on three overlay projects. The warranty covers replacement for these projects and normal snow plow damage. Although VDOT has not paid for any tape replacement, it may pay for replacement markings if there is evidence that the pavement was damaged by snow plow operations. It is likely that VDOT will pay to replace some tape damaged during the winter of 1995-96. The payment could cover up to ½ of the damaged markings. Because the study sites did not require any tape replacement, this analysis did not include any additional costs to VDOT for replacement markings during the warranty period. However, the waffle tape replacement activity is mentioned here to provide a statewide view of the problem. It is hoped that resolution of installation problems will reduce the amount of damaged tape and result in less replacement.

Minimum Retroreflectivity Values

Research is underway in 17 participating states to enable FHWA to adopt minimum retroreflectivity values for pavement markings by 1998. Although a minimum retroreflectivity of 150 $mcd/m^2/lx$ has been discussed, a decision has not been made. It is likely that the estimated service life for waffle tape will be set at about 20 percent of the initial retroreflectivity if the 150 $mcd/m^2/lx$ value is adopted. The minimum retroreflectivity values recommended by FHWA are likely to affect the estimated service life of pavement markings.

Life-cycle Cost Analysis

Based on the life-cycle analysis, one might conclude that VDOT should continue using its current plow arrangement because it is the least costly. But the analysis does not consider that two of the alternatives have the benefit of pavement markings with higher retroreflectivity levels for a longer period. Although brighter or more retroreflective pavement markings are beneficial in delineating travel lanes at night, it is difficult to place a dollar value on this benefit. Therefore, this study did not determine if the additional cost for using wheels with carbide-tipped blades is justified based on this benefit. However, given the investment VDOT has in its pavement markings, considering means to protect it is a good business practice.

The cost analysis is an estimate only and is limited by the assumptions made regarding the estimated service life of the markings, snow plow blades, and castor wheels. The assumptions were based on the best available information.

Other Markings

Although only one type of pavement marking was examined in detail in this study, snow plowing affects all markings. The reduced rate of retroreflectivity deterioration for waffle tape resulting from the alternative plow configurations would likely be applicable to other markings as well.

Limitations of the Study

The failure to collect activity and results data for the control section made comparing the test plow and normal arrangements impossible. Judgments concerning the comparative quality of snow removal were subjective.

Although thermoplastic and paint sites were planned for all three plow arrangements, only waffle tape sites were installed and maintained. Thus, the information on the impact of the plow arrangements was limited to one marking type.

Ideally, this study would have included a substantially larger sample size. To manage a study requiring drives throughs during snow plowing, it was necessary to select a limited number of sites in the vicinity of Charlottesville. However, the number of study sites was sufficient to draw definitive conclusions.

CONCLUSIONS

1. The addition of wheels to plows with carbide-tipped blades prolongs the retroreflectivity and service life of pavement markings. Urethane blades on plows with wheels are even more effective.

2. Carbide-tipped blades without wheels are the least expensive alternative, followed closely by carbide-tipped blades with wheels, and then urethane blades with wheels.

3. Compared to carbide-tipped blades without wheels, carbide-tipped blades with wheels or urethane blades with wheels are effective in removing loose snow. All three blade configurations are effective in removing loose snow.

4. Compared to carbide-tipped blades without wheels, carbide-tipped blades with wheels or urethane blades with wheels are not as effective in removing packed snow.

5. Timely chemical application to prevent snow-pavement bonding is critical to the performance of snow plowing in general and particularly for plowing done with wheel-supported plows.

6. Urethane blades are susceptible to wear through friction. They are not practical for use on second and third priority snow routes where variations in cross slope and soft shoulders bring the blade into contact with the pavement during plowing operations.

7. Using wheels on plows equipped with carbide-tipped blades allows the operator the option of using the plow with wheels for first priority snow removal routes or without wheels for lower priority routes.

8. On wheel-supported plows, proper wheel alignment is critical to proper operation, protection of urethane blades from wear, and reduction of pavement marking scraping. The lack of a standardized connection for connecting snow plow frames to trucks requires modification of the plow, frame, and hitch.

9. It is difficult to measure monetarily the value of increased and prolonged retroreflectivity of pavement markings and more effective snow removal.

RECOMMENDATIONS

1. VDOT should not use urethane blades as a replacement for carbide-tipped blades under current operating conditions.

2. If VDOT continues to make improved (i.e., brighter and more durable) pavement markings a high priority, they should consider using carbide-tipped blades on plows with supports. Other actions that balance the importance of protecting Virginia's pavement marking investment and ensuring effective snow removal, such as restricting the use of heavy equipment for snow removal and providing operator training, should also be considered.

3. If supported plows are adopted for use, options other than wheels to support the plow should be investigated through a series of product evaluations conducted by field personnel.

ACKNOWLEDGMENTS

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APPENDIX A

Snow Blade Requirements

Urethane Blades

The following requirements were developed for purchase of the urethane snow plow blades. These requirements were based on those developed by the Metropolitan Washington Airport Authority for use on snow plows used to maintain runways at National Airport.

Hardness, Shore A	86 durometer minimum
Tear D-470	140 PLI minimum
Die C Tear	540 PLI minimum
Tabor Abrasion	16 mg maximum
Tensile	41400 kPa (6000 psi) minimum

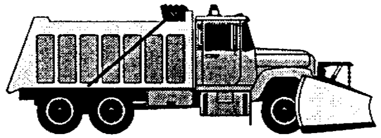
Carbide-Tipped Blades

The following requirements were taken from VDOT's specification for carbide-tipped snow blades:

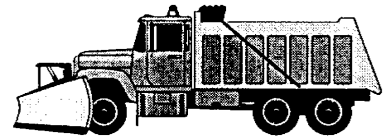
Rockwell Hardness	A Scale 88.5 ± 0.5 (ASTM Designation B-294-64)
Traverse Rupture Strength	Min. 2,400,000 kPa (350,000 psi)
Density	14.1 Min. to 14.6 Max.
Cobalt Content	12.5 to 10 percent

APPENDIX B

Operator Input Form



SNOW PLOWING FIELD ACTIVITY LOG



Location: Route # ________________ From: ______________________________ To: ______________________________

ED # ________________

DATE	TIME	PRECIPITATION								ACTIVITY								PAVEMENT CONDITION								INITIALS
		light rain	rain	freezing rain	sleet	light snow	snow	blowing snow	none	plowing	chemicals	abrasives	none	material type	rate #/LM	where: passing lane	where: travel lane	location	dry	damp	wet	slush	loose snow	packed snow	ice	
																		WHEEL TRACKS								
																		OUTSIDE TRACKS								
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INSTRUCTIONS FOR SNOW PLOWING FIELD ACTIVITY LOG

HEADING, DATE AND TIME

1. **Location: Route #, from and to.** The description should cover the full section assigned for snow removal.
2. **ED#** of the truck. Each truck used in the operations should have log sheets that pertain only to that truck.
3. **Date**. The date should correspond to the first start time entry if the log sheet covers before and after midnight.
4. **Time.** For each pass note the starting time. Specify AM or PM or use a 24-hour clock.

PRECIPITATION DEFINITIONS (check one)

Light rain. Liquid droplets small in size falling at a rate insufficient to result in standing water (puddling) or visible run-off from a road.
Rain. Liquid precipitation falling at a rate sufficient to result in noticeable flow from a road surface or along a road gutter.
Freezing rain. Supercooled droplets of liquid precipitation falling on a surface whose temperature is below or slightly above freezing, resulting in a hard, slick, generally thick coating of ice commonly called glaze or clear ice. Non-supercooled raindrops falling on a surface whose temperature is well below freezing will also result in glaze.
Sleet. A mixture of rain and of snow which has been partially melted by falling through an atmosphere with a temperature slightly above freezing.
Light snow. Snow falling at the rate of less than ½ inch per hour; visibility is not affected adversely.
Snow. Snow falling at the rate of ½ inch per hour or greater; visibility may be reduced.
Blowing snow. Snow picked up by the wind from already deposited accumulations and transported across a road. Sometimes called a "ground blizzard."
None. No precipitation and no blowing snow.

ACTIVITY

Check the **method(s) of treatment**. Make sure this information is completed for all treatments. More than one may be checked.
Check the **lane(s) being treated**. Do not check if no activity is in progress.
When the treatments are **chemical or/and abrasives** treatments, (1) note specifically the material(s) that are being applied (examples: salt, sand, calcium) and (2) note the applications rate(s) as accurate as is possible.

PAVEMENT CONDITION DEFINITIONS (check one)

Dry. No wetting of the pavement surface.
Damp. Light coating of moisture on the pavement but with no visible water drops.
Wet. Road surface saturated with water from rain or meltwater, whether or not resulting in puddling or runoff.
Slush. Accumulation of snow which lies on the pavement and is saturated with water. It will not support any weight when stepped or driven on but will "squish" until the base support is reached.
Loose snow. Unconsolidated snow, i.e., snow lacking intergranular bonds, which can be easily blown into drifts or off of a surface.
Packed snow. The infamous "snowpack" or "pack" which results from compaction of wet snow by traffic or by alternate surface melting and refreezing of the water which percolated through the snow or which flowed from poorly drained shoulders.
Ice. Ice crystals in the form of scales. Needles, feathers or fans or a thin or thick coating of frozen water. Could be caused by frozen dew, rain, freezing rain or ponded water.

APPENDIX C

Storm Histories

The daily accumulation of snow, recorded at the McCormick Observatory on the University of Virginia campus, is provided. The hourly weather observations for each storm are also provided. These observations were made at the Charlottesville Airport. The intermittent data on the pavement temperature were obtained from the VDOT weather station on Route 64 at the Rivanna River Bridge.

Storm of 1/6 to 1/8

Snow accumulation

Period	Amount
1/6-9:00 A.M. to 1/7-9:00 A.M.	440 mm (17.5 in)
1/7-9:00 A.M. to 1/8-9:00 A.M.	90 mm (3.5 in)
1/8-9:00 A.M. to 1/9-9:00 A.M.	0 mm

Also see Tables C1 and C2.

Storm of 1/12

Snow accumulation

Period	Amount
1/11-9:00 A.M. to 1/12-9:00 A.M.	150 mm (6 in)
1/12-9:00 A.M. to 1/13-9:00 A.M.	0 mm

Also see Tables C3 and C4.

Storm of 2/2-2/3

Snow accumulation

Period	Amount
2/1-9:00 A.M. to 2/2-9:00 A.M.	190 mm (7.5 in)
2/2-9:00 A.M. to 2/3-9:00 A.M.	165 mm (6.5 in)
2/2-9:00 A.M. to 2/4-9:00 A.M.	0 mm

Also see Tables C5 and C6.

Table C1. Hourly Weather Observations for Charlottesville Airport: January 6-8, 1996

Day	Hour	Sky Condition	Air Temp (°C)	Wind Dir.	Wind Speed (k/hr)
6	0:00	m	m	m	m
6	1:00	N/A	-4	E	11
6	2:00	m	m	m	m
6	3:00	m	m	m	m
6	4:00	N/A	-4	E	10
6	5:00	N/A	-4	NE	8
6	6:00	Cloudy	-4	E	8
6	7:00	Flurries	-4	E	10
6	8:00	Cloudy	-3	NE	10
6	9:00	Cloudy	-4	E	8
6	10:00	Cloudy	-4	NE	10
6	11:00	Flurries	-3	E	13
6	12:00	Lgt snow	-4	E	8
6	13:00	Cloudy	-4	N	10
6	14:00	Lgt snow	-4	NE	11
6	15:00	Lgt snow	-5	NE	8
6	16:00	Lgt snow	-5	NE	5
6	17:00	Snow	-6	NE	8
6	18:00	Snow	-6	NE	11
6	19:00	Snow	-6	NE	15
6	20:00	Snow	-6	NE	15
6	21:00	Snow	-6	NE	10
6	22:00	Snow	-7	NE	15
6	23:00	Snow	-7	NE	11
7	0:00	m	m	m	m
7	1:00	m	m	m	m
7	2:00	N/A	-8	NE	20
7	3:00	N/A	-8	NE	20
7	4:00	N/A	-9	NE	25
7	5:00	N/A	-9	NE	21
7	6:00	Snow	-9	N	23
7	7:00	Hvy snow	-9	N	20
7	8:00	Hvy snow	-9	N	20
7	9:00	Snow	-9	NE	20
7	10:00	Hvy snow	-8	NE	26
7	11:00	Hvy snow	-8	NE	26

Day	Hour	Sky Condition	Air Temp. (◦C)	Wind Dir.	Wind Speed (k/hr)
7	12:00	Hvy snow	-7	NE	26
7	13:00	m	m	m	m
7	14:00	Snow	-6	m	m
7	15:00	Snow	-5	NE	27
7	16:00	m	m	m	m
7	17:00	Snow	-6	N	27
7	18:00	Snow	-6	NE	20
7	19:00	Snow	-5	N	20
7	20:00	Snow	-7	NW	13
7	21:00	Snow	-7	NW	26
7	22:00	Snow	-6	N	19
7	23:00	m	m	m	m
8	0:00	m	m	m	m
8	1:00	N/A	-6	NW	8
8	2:00	N/A	-6	NW	10
8	3:00	N/A	-6	NW	10
8	4:00	N/A	-6	NW	8
8	5:00	m	m	m	m
8	6:00	m	m	m	m
8	7:00	Cloudy	-6	NW	19
8	8:00	m	m	m	m
8	9:00	Cloudy	-5	NW	19
8	10:00	Cloudy	-4	NW	23
8	11:00	Cloudy	-4	NW	23
8	12:00	Pt sunny	-2	NW	20
8	13:00	m	m	m	m
8	14:00	Sunny	-1	NW	27
8	15:00	Sunny	0	NW	19
8	16:00	Clear	0	NW	16
8	17:00	Clear	-1	W	16
8	18:00	Clear	-2	NW	10
8	19:00	Clear	-1	NW	21
8	20:00	Clear	-3	S	10
8	21:00	m	m	m	m
8	22:00	Clear	-5	SW	23
8	23:00	Pt cldy	-5	SW	16

Table C2. Road Weather Information Station Data, Route 64 at Rivanna River: January 6-8, 1996

Day	Time	Surface Temp. (∘C)	Air Temp. (∘C)	Precip.
6	14:08	-1	-5	Y
6	14:12	-2	1	Y
6	14:25	-2	-5	Y
6	14:30	-2	-5	Y
6	14:36	-2	-5	Y
6	14:42	-2	-5	Y
6	15:02	-2	-5	Y
6	15:17	-3	-6	Y
6	15:45	-3	-5	Y
6	15:50	-3	-5	Y
6	15:56	-4	-5	Y
6	15:59	-4	-5	Y
6	16:16	-3	-5	Y
6	16:19	-3	-5	Y
6	16:22	-3	-5	Y
6	17:09	-4	-6	Y
6	17:19	-4	-6	Y
6	17:20	-4	-6	Y
6	17:50	-4	-6	Y
6	17:56	-4	-6	Y
6	18:02	-4	-6	Y
6	18:05	-4	-6	Y
6	18:17	-4	-6	Y
6	18:23	-4	-6	Y
6	18:35	-4	-6	Y
6	18:58	-4	-6	Y
6	19:01	-4	-6	Y
6	19:03	-4	-6	Y
8	13:53	3	2	Y
8	13:55	3	2	Y
8	14:07	3	3	Y
8	14:08	3	3	N
8	14:14	3	2	N
8	14:29	3	2	N
8	14:37	3	2	N
8	14:41	3	2	N
8	14:44	3	2	N
8	14:47	3	2	N

Day	Time	Surface Temp. (◦C)	Air Temp. (◦C)	Precip.
8	14:54	2	3	N
8	14:55	2	3	N
8	14:58	2	3	N
8	15:01	3	3	N
8	16:41	-3	-2	N
8	16:47	-3	-2	N
8	16:53	-3	-2	N
8	16:56	-3	-2	N
8	16:59	-4	-2	N
8	17:08	-4	-3	N
8	17:14	-4	-3	N
8	17:17	-4	-3	N
8	17:23	-4	-3	N
8	17:26	-4	-3	N
8	17:30	-4	-3	N
8	17:33	-4	-3	N
8	17:34	-4	-3	N
8	17:49	-5	-4	N
8	18:01	-5	-4	N
8	18:04	-5	-4	N
8	18:42	-6	-5	N
8	18:45	-6	-5	N
8	18:59	-6	-5	N
8	19:00	-6	-5	N
8	19:01	-6	-5	N
8	19:02	-6	-5	N

Table C3. Hourly Weather Observations for Charlottesville Airport: January 12, 1996

Day	Hour	Sky Condition	Air Temp (°C)	Wind Dir.	Wind Speed (k/hr)
12	0:00	m	m	m	m
12	1:00	m	m	m	m
12	2:00	N/A	-7	CALM	0
12	3:00	m	m	m	m
12	4:00	N/A	-7	NE	13
12	5:00	N/A	-7	NE	15
12	6:00	Snow	-7	N	20
12	7:00	m	m	m	m
12	8:00	m	m	m	m
12	9:00	m	m	m	m
12	10:00	Lgt snow	-6	CALM	0
12	11:00	Lgt snow	-4	CALM	0
12	12:00	Cloudy	-2	N	10
12	13:00	Mo sunny	-1	NW	11
12	14:00	Mo sunny	1	NW	10
12	15:00	Mo sunny	2	NW	10
12	16:00	Mo cldy	2	NW	13
12	17:00	Clear	2	NW	21
12	18:00	Clear	1	NW	11
12	19:00	Clear	-1	SW	11
12	20:00	Clear	-3	SW	11
12	21:00	Pt cldy	-1	NW	13
12	22:00	m	m	m	m
12	23:00	m	m	m	m

Table C4. Road Weather Information Station Data, Route 64 at Rivanna River: January 12, 1996

Day	Time	Surface Temp. (◦C)	Air Temp. (◦C)	Precip.
12	7:31	-6	-7	Y
12	7:37	-6	-7	Y
12	7:40	-6	-7	Y
12	7:46	-6	-7	Y
12	7:49	-6	-7	Y
12	7:55	-6	-7	Y
12	8:04	-6	-7	Y
12	8:15	-6	-6	Y
12	8:21	-6	-6	Y
12	8:27	-6	-6	Y
12	8:33	-6	-6	Y
12	8:36	-6	-6	Y
12	9:08	-5	-6	Y
12	9:11	-5	-6	Y
12	9:29	-5	-6	Y
12	10:00	-4	-5	Y
12	17:40	-1	-2	N
12	17:45	-1	-2	N
12	17:46	-2	-2	N
12	17:49	-1	-2	N
12	17:51	-2	-2	N
12	17:52	-1	-2	N
12	17:53	-2	-2	N
12	17:59	-2	-2	N
12	18:00	-2	-2	N
12	18:05	-2	-2	N
12	18:17	-2	-2	N
12	18:19	-2	-2	N
12	18:22	-2	-2	N
12	18:25	-2	-2	N
12	18:28	-2	-2	N
12	18:34	-2	-3	N
12	18:39	-3	-3	N
12	18:52	-3	-3	N
12	18:55	-3	-3	N
12	18:59	-3	-3	N

Table C5. Hourly Weather Observations for Charlottesville Airport: February 2-3, 1996

Day	Hour	Sky Condition	Air Temp (°C)	Wind Dir.	Wind Speed (k/hr)
2	0:00	m	m	m	m
2	1:00	m	m	m	m
2	2:00	N/A	-6	CALM	0
2	3:00	N/A	-6	CALM	0
2	4:00	N/A	-6	CALM	0
2	5:00	m	m	m	m
2	6:00	Snow	-6	CALM	0
2	7:00	Snow	-6	CALM	0
2	8:00	Snow	-6	CALM	0
2	9:00	Snow	-6	CALM	0
2	10:00	Snow	-5	CALM	0
2	11:00	Lgt snow	-4	CALM	0
2	12:00	m	m	m	m
2	13:00	m	m	m	m
2	14:00	m	m	m	m
2	15:00	m	m	m	m
2	16:00	m	m	m	m
2	17:00	m	m	m	m
2	18:00	m	m	m	m
2	19:00	Snow	-6	NE	15
2	20:00	m	m	m	m
2	21:00	m	m	m	m
2	22:00	Snow	-7	NE	20
2	23:00	N/A	-8	NE	10
3	0:00	m	m	m	m
3	1:00	N/A	-8	N	5
3	2:00	N/A	-8	N	5
3	3:00	N/A	-8	N	10
3	4:00	N/A	-9	N	8
3	5:00	N/A	-9	N	8
3	6:00	Cloudy	-9	NE	8
3	7:00	Cloudy	-9	NE	10
3	8:00	Mo cldy	-9	NE	8
3	9:00	Pt sunny	-9	NE	8
3	10:00	Pt sunny	-8	NE	10

Day	Hour	Sky Condition	Air Temp (∘C)	Wind Dir.	Wind Speed (k/hr)
3	12:00	Cloudy	-7	NE	11
3	13:00	Cloudy	-6	NE	10
3	14:00	Cloudy	-6	NE	11
3	15:00	Cloudy	-6	NE	10
3	16:00	Cloudy	-6	NE	15
3	17:00	Cloudy	-7	CALM	0
3	18:00	Cloudy	-7	CALM	0
3	19:00	Cloudy	-8	NE	10
3	20:00	Cloudy	-8	NE	9
3	21:00	Cloudy	-8	CALM	0
3	22:00	Cloudy	-9	CALM	0
3	23:00	N/A	-9	CALM	0

Table C6. Road Weather Information Station Data, Route 64 at Rivanna River: February 2-3, 1996

Day	Time	Surface Temp. (◦C)	Air Temp. (◦C)	Precip.
2	3:46	-4	-6	Y
2	3:49	-4	-6	Y
2	3:50	-4	-6	Y
2	4:13	-4	-6	Y
2	4:22	-4	-6	Y
2	4:37	-4	-6	Y
2	4:40	-4	-6	Y
2	4:42	-4	-6	Y
2	5:03	-4	-6	Y
2	5:06	-4	-6	Y
2	5:36	-4	-6	Y
2	5:44	-4	-6	Y
2	5:50	-4	-6	Y
2	6:08	-4	-6	Y
2	6:20	-4	-6	Y
2	7:33	-4	-6	Y

APPENDIX D

Snow Blade Histories

Section A
Rt 64 From Albemarle Co. Line To Rt 607 (Sites 1 & 4)
Test Section
Urethane Blades (with wheels)

ED 50430

December 1995		Worked during two storms (12/9, 12/13-14). No plowing undertaken.
1/6	12N-8P	No plowing undertaken.
1/6-7	8P-8A	Plowed loose snow 4 times in passing lane.
1/7	8A-8P	Plowed packed snow 2 times in passing lane.
1/7-8	8A-8A	Plowed packed snow 3 times in passing lane.
1/8	8A-8P	No plowing undertaken.
1/8-9	8P-8A	No plowing undertaken.
1/11		2 hours kicking back snow on ramps and shoulders. Blade switched to plow left. Blade no longer supported by wheels. Blade wore down to moldboard on right end. **Blade changed**.
1/11-12	8P-8A	Plowed loose snow 1 time in passing lane.
1/12	8A-12N	Plowed loose snow 1 time in passing lane.
	2P-3P	Plowed back along 64, switched angle of blade 3 times.
	4P-5P	Plowed on secondary. Plow tipped forward numerous times. Operator indicates this occurred more often than when plow not supported by wheels. Flipping of plow does not damage blade since plow returns to proper position as soon as truck stops.
2/2	12M-8A	Plowed loose snow 2 times in passing lane.
	8A-8P	Plowed loose snow 1 time in the passing lane.
2/2-3	8P-8A	Plowed packed snow 3 times in passing lane.
2/3	8A-8P	Plowed packed snow 1 time in passing lane.

ED 58486

December 1995		Worked storm on 12/9. No plowing undertaken. Worked 12/13. No plowing undertaken.
1/6	12N-8P	No data.
1/6-7	8P-8A	Plowed loose snow 3 times in both lanes.
1/7	8A-8P	No data.
1/7-8	8P-8A	No data.
1/8	8A-8P	No data.
1/11-12	8P-8A	Plowed loose snow 1 time in travel lane.
1/12	8A-8P	No data.
	2:30 P	Blade worn down, needs turning. Has not been turned or replaced as of this time. Wheels OK.

2/2	12M-8A	Plowed loose snow 2 times in passing lane.
	8A-8P	No data.
2/2-3	8P-8A	Plowed loose snow 2 times in passing lane.
2/3	8A-8P	No data.
2/5		Wheels worn. Left 2 8" wheels as replacements. Blade has been turned once.

ED 61973

December 1995		Worked storm on 12/9 and 12/13. Plowed slush off road once.
1/6	8A-8P	No data.
1/6-7	8P-8A	Plowed packed snow 1 time in travel lane. Plowed loose snow 3 times in travel lane.
1/7	8A-8P	No data.
1/7-8	8P-8A	Plowed packed snow 2 times in travel lane.
1/8	8A-8P	No data.
1/8-9	8P-8A	No plowing undertaken
1/11-12	8P-8A	Chemicals on loose snow. No plowing undertaken.
1/12	8A-8P	No data.
	2:30P	Blade worn on left side. Plow usually pushes right. Blade has been turned once, needs to be turned again
2/2	12M-8A	No data.
2/2	8A-8P	Plowed loose/packed snow 1 time in passing lane.
2/2-3	8P-8A	No data.
2/3	8A-8P	No data.
2/5		Using second blade, second side.

Section B
Rt 64 From 607 To Goochland Co. Line (Sites 2 & 3)
Test Section
Carbide-tipped Blade (with wheels)

ED 58154

December 1995		Worked storms of 12/9, 12/13, and 12/19-20. Plowed slush off road once on 12/9.
1/6	12N-8P	No plowing undertaken.
1/6-7	8P-8A	Plowed packed snow 6 times in passing lane.
1/7	8A-8P	Plowed packed snow 3 times in both lanes.
1/7-8	8P-8A	Plowed loose/packed snow 6 times in passing lane.
1/8	8A-8P	Plowed loose snow 1 time in both lanes (9 AM).
1/10	12:30P	Plowed shoulders, pavement dry.

1/11-12	8P-8A	Plowed loose/packed snow 4 times in passing lane.
1/12	8A-8P	Plowed packed snow 1 time in travel lane.
2/2	12M-8A	Plowed packed/loose snow 2 times in passing lane.
	8A-8P	Plowed/packed/loose snow 1 time in passing lane Plowed slush 1 time in passing lane.
2/2-3	8P-8A	Plowing loose/packed snow 5 times in passing lane.
2/3	8A-8P	No data.

ED 52313

December 1995		Worked 12/13. No plowing undertaken.
1/6	12N-8P	No data.
1/6-1/7	8P-8A	Plowed packed snow 5 times in travel lane.
1/7	8A-8P	No data.
1/7-8	8P-8A	No data.
1/8	8A-8P	No data.
1/11-12	8P-8A	No plowing undertaken.
1/12	8A-8P	Plowed packed snow 1 time in travel lane.
2/2	12M-8A	Plowed loose snow 3 times in travel lane.
2/2	8A-8P	Plowed loose snow 4 times in travel lane. Plowed loose snow 2 times in passing lane. Plowed slush 1 time in travel lane.
2/2-3	8P-8A	No data.
2/3	8A-8P	Plowed slush 1 time in passing lane.

ED 62184

December 1995		Worked storm of 12/13. No plowing undertaken.
1/6	12N-8P	No data.
1/6-7	8P-8A	Plowed packed snow 4 times in travel lane. Operator noted truck won't steer around corners well with plow down.
1/7	8A-8P	No report.
1/7-8	8P-8A	Plowed loose and packed snow 3 times in travel lane.
1/8	8A-8P	No data.
1/10	12:23 P	Plowing shoulders, pavement dry.
1/11-12		No data.
1/12		Truck broke down overnight. Wheels are wearing badly.
1/14		Replaced left wheel on plow.
2/2	12M-8A	Plowed loose/packed snow 3 times in travel lane.
	8A-8P	Plowed loose snow 1 time in travel lane.
2/2-3	8P-8A	No data.

2/3	8A-8P	No data.
2/5		Right wheel worn badly. (Replaced after 2/6).

Section E
Rt 29 From 64 To 692 (Site 9)
Test Section
Urethane Blade (with wheels)

ED 00569 (Bridge Truck)

1/6	8A-8P	Plowed loose snow 1 time in passing lane.
1/6-7	8P-8A	No data.
1/7	8A-8P	Plowed loose snow 2 times in passing lane.
1/7-8	8P-8A	Plowed loose/packed snow 2 times in both lanes.
1/8	8A-8P	Plowed packed snow 1 time in both lanes.
		Plowed slush 1 time in both lanes.
1/11	Day	Blade has not been changed on this truck. Wheels are OK.
1/11-12	8P-8A	Plowed loose snow 2 times in passing lane.
1/12	8A-8P	No data.
	11:40A	Blade has not been changed on this truck. Wheels are OK.
2/2	12 M-8A	Plowed loose snow in both lanes.
2/2	8A-8P	No data.
2/2-3	8P-8A	No data.
2/3	8A-8P	No data.
2/4		First blade turned to second side. Wheels show little wear.

ED 62194

1/6	12N-8P	No plowing undertaken.
1/6-7	8P-8A	Plowed loose snow 1 time in travel lane.
		Plowed packed snow 1 time in travel lane.
1/7	8A-8P	Plowed loose snow 2 times in travel lane.
1/7-8	8P-8A	No data.
1/8	8A-8P	No data.
1/10		Blade has been reversed and replaced as of this date. Truck plowed stabilized shoulder prior to this and wheels sank into ground, which caused considerable blade wear.
1/11-1/12		No data.
2/2	12M-8A	No data.
2/2	8A-8P	No data.
2/2-3	8P-8A	Plowed loose snow 1 time in travel lane.
		Plowed packed snow 1 time in travel lane.
2/3	8A-8P	No data.
2/4		Using second blade. Blade turned over this date. Wheels show little wear.

ED 61779

1/6	12N-8P	Plowed loose snow 1 time in both lanes.
1/6-7	8P-8A	No data.
1/7	8A-8P	No data.
1/7-8	8P-8A	No data.
1/8	8A-8P	No data.
1/12		No data.
2/2	12M-8P	No data.
2/2	8A-8P	Plowed loose snow 12 times in passing lane.
2/2-3	8P-8A	No data.
2/3	8A-8P	Plowed slush 2 times in passing lane.

Section F
Rt 250 From Charlottesville SCL To 64 (Site 10)
Control Section
Carbide-tipped Blade (without wheels)

ED 61551

1/6	8A-8P	Plowed packed snow. Number of times unknown.
1/6-7	8P-8A	No data.
1/7	8A-8P	No data.
1/7-8	8P-8A	No data.
1/8	8A-8P	No data.
1/12		No data.
2/2-2/3		No data.

ED 52319

December 1995	Worked 12/7 and 12/9. Plowed slush off road once each day.
1/6-1/8	No data.
1/12	No data.
2/2-2/3	No data.

APPENDIX E

Comparison of Blade Performance in Sections A and B

STORM 1: JANUARY 6 -8, 1996

STORM		ACTIVITY				CONDITION			
Date	Time	Section A		Section B		Section A		Section B	
		Activity	Amount	Activity	Amount	Through	Passing	Through	Passing
01/06/96	9:35			plowing				packed snow	
01/06/96	16:15	chemicals	500				loose snow		
01/06/96	17:30	chemicals	500			loose snow			
01/06/96	19:00					packed snow	packed snow		
01/06/96	19:20							packed snow	packed snow
01/06/96	20:00			plowing					packed snow
01/06/96	21:15	plowing				packed snow	packed snow		
01/06/96	21:30			plowing				packed snow	
01/06/96	22:00			plowing					packed snow
01/06/96	22:30	plowing					loose snow		
01/06/96	22:30	plowing				loose snow	loose snow		
01/06/96	22:45			plowing				packed snow	
01/07/96	0:05			plowing					packed snow
01/07/96	1:00			plowing				packed snow	
01/07/96	1:00	plowing				loose snow	loose snow		
01/07/96	1:15			plowing				packed snow	
01/07/96	1:30	plowing					loose snow		
01/07/96	2:00			plowing					packed snow
01/07/96	2:30			plowing				packed snow	
01/07/96	3:00	plowing					loose snow		
01/07/96	3:00	plowing				loose snow	loose snow		
01/07/96	3:25			plowing				packed snow	
01/07/96	4:00			plowing					packed snow
01/07/96	5:20			plowing				packed snow	
01/07/96	5:30			plowing				packed snow	
01/07/96	6:00			plowing					packed snow
01/07/96	6:00	plowing					loose snow		
01/07/96	10:30			plowing				packed snow	packed snow
01/07/96	12:00	plowing				packed snow	packed snow		
01/07/96	16:30			plowing				packed snow	packed snow
01/07/96	18:00			plowing					packed snow
01/07/96	19:30	plowing				packed snow	packed snow		
01/07/96	20:00			plowing					packed snow
01/07/96	21:00	plowing					packed snow		
01/07/96	21:00	plowing				packed snow			
01/07/96	22:00			plowing					packed snow
01/07/96	22:30			plowing				packed snow	
01/08/96	0:10			plowing					packed snow
01/08/96	1:00	plowing				packed snow			

STORM		ACTIVITY				CONDITION			
Date	Time	Section A		Section B		Section A		Section B	
		Activity	Amount	Activity	Amount	Through	Passing	Through	Passing
01/08/96	1:30	plowing				loose snow			
01/08/96	2:10			plowing				packed snow	
01/08/96	2:30			plowing					packed snow
01/08/96	3:00	plowing				loose snow			
01/08/96	4:00			plowing					packed snow
01/08/96	4:00	plowing				packed snow			
01/08/96	6:00			plowing					packed snow
01/08/96	6:00	plowing				loose snow			
01/08/96	6:20			plowing				packed snow	
01/08/96	9:00			plowing				loose snow	loose snow
01/08/96	11:00			chemicals	unknown				packed snow
01/08/96	13:00	plowing					packed snow		
01/08/96	15:00			chemicals	unknown			packed snow	
01/08/96	15:30	abrasives	unknown			packed snow			
01/08/96	15:30					wet	wet		
01/08/96	15:35								wet
01/08/96	15:35			abrasives	unknown			packed snow	
01/08/96	16:00	plowing					packed snow		
01/08/96	18:25							packed snow	packed snow
01/08/96	22:00					packed snow			
01/08/96	22:00					packed snow	packed snow		

STORM 2: JANUARY 12, 1996

STORM		ACTIVITY				CONDITION			
Date	Time	Section A		Section B		Section A		Section B	
		Activity	Amount	Activity	Amount	Through	Passing	Through	Passing
01/12/96	2:30			chemicals	unknown				loose snow
01/12/96	2:30			chemicals	unknown				loose snow
01/12/96	2:30			chemicals	unknown				loose snow
01/12/96	3:00	chemicals	500				loose snow		
01/12/96	3:00	chemicals	500			loose snow			
01/12/96	3:20	chemicals	unknown			loose snow			
01/12/96	3:45			plowing					loose snow
01/12/96	4:50			plowing					packed snow
01/12/96	5:00	plowing					loose snow		
01/12/96	5:00	plowing				loose snow			
01/12/96	5:30								packed snow
01/12/96	5:30							packed snow	
01/12/96	6:00			plowing					packed snow
01/12/96	7:15			plowing					packed snow
01/12/96	8:15			plowing				packed snow	
01/12/96	8:15			plowing				packed snow	
01/12/96	8:15			chemicals	unknown			packed snow	packed snow
01/12/96	8:30	plowing				loose snow	loose snow		
01/12/96	10:30			chemicals	unknown			packed snow	packed snow
01/12/96	11:00	chemicals	500			loose snow	loose snow		

STORM 3: FEBRUARY 2-3, 1996

STORM		ACTIVITY				CONDITION			
Date	Time	Section A		Section B		Section A		Section B	
		Activity	Amount	Activity	Amount	Through	Passing	Through	Passing
02/02/96	1:00	chemicals	500				loose snow		
02/02/96	2:00			chemicals	unknown				loose snow
02/02/96	2:15			chemicals	unknown				packed snow
02/02/96	2:20			chemicals	unknown			loose snow	
02/02/96	3:15	plowing				shoulders			
02/02/96	3:30			plowing					packed snow
02/02/96	3:30			plowing				packed snow	
02/02/96	3:30			plowing				packed snow	
02/02/96	3:30	plowing					loose snow		
02/02/96	4:45			plowing				packed snow	
02/02/96	5:00			plowing				packed snow	
02/02/96	5:00	plowing					loose snow		
02/02/96	5:00	plowing				shoulders			
02/02/96	6:00			plowing					packed snow
02/02/96	6:30			plowing				packed snow	
02/02/96	8:00	plowing					packed snow		
02/02/96	8:30			plowing				loose snow	
02/02/96	9:00			plowing					packed snow
02/02/96	9:00			plowing				packed snow	
02/02/96	9:30			plowing					packed snow
02/02/96	10:30			plowing				loose snow	
02/02/96	11:15	plowing				shoulders			
02/02/96	11:45			plowing				packed snow	
02/02/96	12:30			plowing					loose snow
02/02/96	13:30			plowing					packed snow
02/02/96	15:10			plowing				slush	
02/02/96	16:00							loose snow	loose snow
02/02/96	19:00			plowing				loose snow	
02/02/96	20:00			plowing					packed snow
02/02/96	21:00	plowing					loose snow		
02/02/96	21:30	plowing				shoulders			
02/02/96	23:00			plowing					packed snow
02/03/96	1:00			plowing					packed snow
02/03/96	1:00	plowing					loose snow		
02/03/96	1:30			chemicals	unknown				packed snow
02/03/96	2:00	plowing				shoulders			
02/03/96	3:30			plowing					packed snow
02/03/96	4:30	plowing				shoulders			
02/03/96	7:00			plowing					packed snow

STORM		ACTIVITY				CONDITION			
Date	Time	Section A		Section B		Section A		Section B	
		Activity	Amount	Activity	Amount	Through	Passing	Through	Passing
02/03/96	9:10			chemicals	unknown			packed snow	
02/03/96	10:00	chemicals	500				loose snow		
02/03/96	10:10			chemicals	unknown			packed snow	packed snow
02/03/96	13:30			chemicals	unknown			slush	
02/03/96	15:00			plowing					slush

APPENDIX F

Operator and Supervisor Comments on Snow Removal Quality

Date	Time	Comment
1/6	11 P.M.	Followed two trucks plowing with urethane blades on Route 29 from 1104 to Route 692. The truck in the travel lane is leaving approximately 3/4" of packed snow on the surface. The truck in the passing lane is clearing the surface of snow. The snow in the travel lane is packed and bonded to the surface. The snow in the passing lane is loose and not bonded to the surface. (DSR)
1/8	3 P.M.	During the storm, the urethane blades used on 29 from 1104 to 692 rode over the surface and would not cut the packed snow. The blade used on the travel lane wore badly and needs to be replaced. (Jimmy Howe)
1/8	4 P.M.	During the storm, the carbide blades on wheel-supported plows used on 64 from 607 to the Goochland County Line rode over the snow. They would not cut off the packed snow. (Operators at Ferncliff Headquarters)
1/11		The urethane blades tend to ride on top of the snow, if packed. The operators feel like they are using a greater amount of chemical than usually necessary to keep a bond from forming between snow and pavement and to allow the blade to push it off.
1/12	10 A.M.	Visual comparison of 29 from 1104 to 692 (test section) to 250 from Charlottesville City Limits to 1104 (control section) indicates that plowing on the test section is as good a quality or better than the control section. Snow on the control section is bonded to the surface, indicating insufficient chemical was applied prior to plowing. The test section gives evidence of having been chemically treated.
1/12	11 A.M.	Route 692, from 29 to Batesville in Albemarle County, plowed with a urethane blade. Blade removed the loose snow, but not the packed snow bonded to the pavement. The operator's opinion was that a carbide blade without wheels would not have done better. (Mike Watson)
1/12	5 P.M.	Vehicle ED 50430 plowed using a urethane blade on the secondary system for 20 to 25 miles. The road conditions were loose snow, fallen that day covering packed snow from the previous snow storm (January 6 to 8). The packed snow was bonded to the road surface. The blade removed the loose snow but would not cut the packed snow. The wheels on the plow penetrated the packed snow and would often create a "trough" in the snow but the urethane blade tended to ride on top of the packed snow. (DSR)
2/5		The urethane blade with wheels leaves a thin layer of snow and the thickness of this layer increases with each subsequent plowing. (Jimmy Howe)
2/5		The carbide blade with wheels is riding on top of the snow. Removal of snow from the pavement is not as good as on the next section east, which is plowed with carbide blades without wheel supports. (Operators at Ferncliff)