**3M Stamark Polyurea
Liquid Pavement Marking Series 1200
In Grooved Pavement Surfaces
South Burlington, Vermont
Final Report**

July 2007

**Report 2007 - 10
Reporting on Work Plan 2002-R-1**

State of Vermont
Agency of Transportation
Materials and Research Section

Prepared by:

Nicole Crum, EI
Research Technician

Jennifer M. V. Fitch, EI
Research Engineer

Reviewed by:

William E. Ahearn, PE
Materials and Research Engineer

Date: Aug 2, 2007

TABLE OF CONTENTS

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
2007-10		

4. Title and Subtitle	5. Report Date
3M Stamark Polyurea, Liquid Pavement Marking Series 1200 in Grooved Pavement Surfaces South Burlington, VT	July 2007
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Nicole Crum, Jennifer Fitch	2007-10

9. Performing Organization Name and Address	10. Work Unit No.
Vermont Agency of Transportation Materials and Research Section National Life Building Drawer 33 Montpelier, VT 05633-5001	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Federal Highway Administration Division Office Federal Building Montpelier, VT 05602	Final (2003-2007)
	14. Sponsoring Agency Code

15. Supplementary Notes

Reporting on Work Plan 2002-R-1

16. Abstract

In an effort to prolong the service life of pavement markings, the Vermont Agency of Transportation (VTrans) engaged in a study to examine the effectiveness of recessing pavement markings, otherwise known as the application of markings into a groove in the pavement as in theory this should protect the pavement marking binder and reflective elements from damage produced by winter maintenance practices and abrasion from tires. After only 0.75 years of service, all surface applied white edge lines on this project had fallen below the FHWA Recommendations, while it took nearly 2.14 years of service for the recessed white edge lines to fall below FHWA Recommendation.

The data evidenced a large drop in readings on all materials following the first winter season, although the drop was not as significant in the recessed markings as it was in the surface applied markings. Due to the shearing effects produced by winter maintenance practices, the larger diameter beads, or ceramic elements, may have become dislodged or shaved off, resulting in a great loss of retroreflectivity. Generally it can be stated that recessing pavement markings can be considered beneficial for extending the performance of the pavement marking. In addition, recessing markings appears to be highly cost effective in terms of service life.

Recessing polyurea markings is recommended along limited access highways and in high AADT locations.

17. Key Words	18. Distribution Statement
Pavement Markings Polyurea Recessing	No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. Pages	22. Price
Unclassified	Unclassified	15	

INTRODUCTION

Cost effective and durable pavement markings are important for the safety of the traveling public. Longitudinal markings delineate driving lanes, segregate traffic in opposing directions and indicate where passing is permissible. In addition to the application of the binder, reflective elements are dropped onto marking materials during installation in order to assure visibility during evening hours when there is typically little to no contribution from ambient lighting. However, following application, the binder and reflective properties are subject to wear and abrasion from vehicle tires and winter maintenance practices as well ultraviolet sunlight and fading pigments. Over time, these markings decay resulting in a loss of both daytime and nighttime visibility.

A statewide pavement marking durability assessment was recently performed along with a subsequent report which outlines major variables that attribute to the rate of decay. Corollary statistics indicate that age and winter maintenance practices were found to significantly affect retroreflectivity of pavement markings as well as wearing of the binder. Typically, durable pavement markings are applied to the surface of newly constructed roadway. As such, the markings protrude from the surrounding pavement making them more susceptible to rapid wear from traffic and snow plows. In an effort to prolong the service life, the Vermont Agency of Transportation (VTrans) engaged in a study to examine the effectiveness of recessing pavement markings, otherwise known as the application of markings into a groove in the pavement. In a recent study conducted by the Colorado Department of Transportation, it was concluded "that placing lane markings in shallow grooves in the pavement results in considerably longer marking life, making the highway safer for drivers."

In order to conduct a reliable analysis, VTrans utilized two pavement marking application methods, surface applied and recessed, along with a proprietary 15 mil liquid polyurea pavement marking material, on a newly constructed paving project on Interstate 189 between the towns of Burlington and South Burlington in the summer of 2003. The objective of this research initiative was to evaluate the performance of both pavement-marking methods in terms of durability and retroreflectivity. The following final report assesses the overall performance of the two pavement marking methods in terms of wear and retroreflectivity, otherwise known as luminance. This report also contains information related to the experimental method of placement and summarizes all surveillance and testing methods, data collection results and associated findings.

PRODUCT DETAILS

As previously stated, markings are typically applied directly to the surface of the pavement leaving them exposed to tire treads and other wear, particularly plow trucks. In an attempt to prevent resulting abrasion and successive decay, a new construction method was developed, known as recessing. This is accomplished by grooving the surface of the pavement to a depth of 40 mils (± 10 mils). It was hypothesized that this method would protect the reflective glass beads from shearing effects produced by winter maintenance practices as well as abrasion. However, other variables, such as sunlight and fading pigments were considered constant for all markings and will not be addressed furtherer.

A durable marking material manufactured by the Traffic Control Division of 3M, known as Stamark Liquid Pavement Marking (LPM) Series 1200, was utilized throughout the entire length of this investigation in order to provide consistency between the recessed and surface applications. In general, polyurea is a two component system composed of 100% polyurea coating materials containing binder, pigments and filler, which cure rapidly to hardness following application. This marking material contains proprietary reflective substrate, known as elements, and glass beads for long term high performance retroreflectivity. According to the manufacturer, the "microcrystalline beads have twice the crush strength as compared to standard glass beads and retain their ability to reflect to unprecedented levels." It should be noted that the microcrystalline ceramic elements are much larger in diameter, roughly 1200 to 1400 microns, as compared to the standard AASHTO (American Association of State Highway and Transportation Officials) Type 1 glass beads with a maximum gradation of 850 microns. Previous studies have shown that larger beads usually require an increased application thickness to ensure adequate adhesion. Product literature indicates a no track time of 3 to 10 minutes when tested in accordance with the American Society for Testing Materials (ASTM) D-711, "Test Method for No-Pick-Up Time of Traffic Paint." According to the manufacturer, the pavement marking material displays high initial and sustained long-term retroreflectivity along with a low application temperature of 40^{o}F. For optimum performance, the manufacturer recommends an application thickness of 18-20 mils for a new asphalt surface.

Specialized equipment is necessary for the application of the markings. Prior to application, any existing pavement markings must be removed to expose a minimum of 8 percent of the pavement surface below the old marking. For application on a newly constructed roadway, the pavement surface must be free of dirt and oils. According to the product literature, the pavement marking can be applied to new asphalt pavement as soon as the material has cooled and can support the weight and movement of necessary equipment.

PROJECT DETAILS

In accordance with the workplan, WP 2002-R-1, "3M Stamark Polyurea, Liquid Pavement Marking Series 1200 in Grooved Pavement Surfaces," the LPM markings were applied to the Burlington/South Burlington IM 189-3(36) project in the summer of 2003. As shown in Table 1, the markings, including all edge and skip lines in the westbound (WB) lanes were recessed from mile marker (MM) 0.334 to MM 0.900 and surface applied from MM 0.900 to MM 1.443. The markings in the eastbound (EB) lanes were to be applied in a similar configuration, recessed from MM 0.000 to MM 0.700 and surfaced applied from MM 0.700 to MM 1.492. Figure 1 displays this configuration below. Please note that test site locations are denoted within the figure.

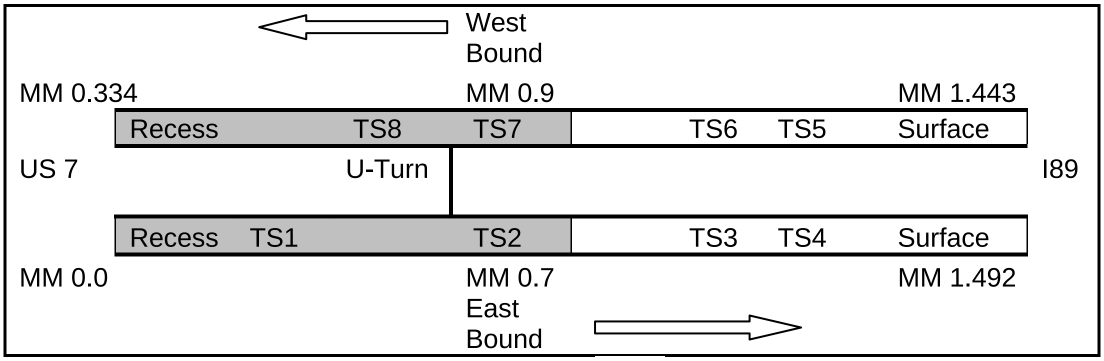

Figure 1 – I-189 LPM Series 1200 Test Location

The construction project included cold planing and resurfacing of both the eastbound and westbound lanes and interchange ramps with a leveling course and Type III Superpave wearing course, pavement markings, guardrails, signs and other incidental items. It is important to note that a Type III wearing course contains a nominal aggregate size of ½" resulting in a rougher pavement surface as compared to a Type IV Superpave wearing course which contains a nominal aggregate size of 3/8". A roughened pavement surface will distribute line striping substrates over a larger surface area, generating an inconsistent thickness or inadequate thickness for the larger diameter beads potentially resulting in premature bead loss. However, this is consistent for all pavement markings on this project. The 2004 average annual daily traffic (AADT) along I-189 in South Burlington was 38,200. This is a high AADT for Vermont which means that the markings in this area are subjected to higher amounts of abrasion from vehicle tires as compared to markings in lower AADT locations.

Burlington-South Burlington Placement Method Locations			
Section Type	**Mile Marker**	**Lane**	**Total Length**
Recessed	0.000 to 0.700	EB	0.700
Recessed	0.334 to 0.900	WB	0.566
Surface Applied	0.700 to 1.492	EB	0.792
Surface Applied	0.900 to 1.443	WB	0.543

Table 1 – Pavement Marking Summary

INSTALLATION

Pavement application was completed by F. W. Whitcomb Construction Corp. on Wednesday, June 11, 2003 in the eastbound lane and Sunday, June 22, 2003 in the westbound lane. Striping and groove installation operations were performed by L & D Safety Markings from Berlin, Vermont. Preparation of the roadway for the application of the pavement markings began on Sunday, June 29th, 2003. This involved milling the pavement with specialized equipment to a depth of 40 mils +/- 10 mils in the areas designated to be recessed, as shown in Figure 2, for all of the longitudinal markings including the right, left and center skip lines. Following recessing activities, heavy rain postponed the application of the LPM markings.

Application of the markings commenced on the evening of Monday, June 30, 2003. All markings were applied following the evening rush hour due to the high traffic volume. Weather conditions were clear with temperatures ranging from 78°F at 6:00 PM to 64°F at midnight. Installation of the yellow edge line in the WB lane between MM 1.433 to MM 0.334 began at 7:40 PM, as displayed in Figure 3. Immediately after placement of the WB yellow edge line, striping of the yellow edge line continued in the EB lane from MM 0.000 to MM 1.492. Application of the yellow edge line was completed by 8:30 PM. Installation of the white edge lines began at approximately 10:00 PM, as shown in Figure 4. Research and Development staff observed the placement of the EB white edge line until approximately 10:15 PM. All markings were completed before daybreak on Tuesday, July 1, 2003.

Figure 2- Recess for Yellow Edge Line

Figure 3-Yellow Edge Line Application

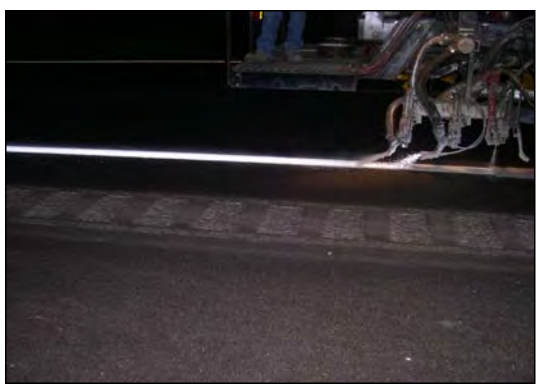

Figure 4- White Edge Line Application

Roadway and weather conditions greatly affect the rate of cure and resulting performance. In accordance with the 2006 Vermont Agency of Transportation's "Standard Specification for Construction," 646.04, "the temperature of the surface to be painted shall be a minimum of 50^{o}F and the ambient air temperature shall be 50^{o}F and rising." As was noted above, the ambient temperature during installation ranged from 64° F to 78° F, which is clearly acceptable and indicates that the ambient and pavement conditions were ideal for proper curing resulting in optimum performance of the pavement markings.

SURVEILLANCE AND TESTING

In accordance with the work plan, eight test sites were established throughout the length of the project in both the recessed and surface applied areas for the collection of retroreflectivity readings in accordance with ASTM E 1710-97, “Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer” and durability, in accordance with ASTM D 913-03, “Evaluating Degree of Resistance to Wear of Traffic Paint.” Each test site was identified in an area with good sight distance on a straight away and consisted of a total length of 40 feet with data collection conducted at 10 foot intervals starting from the beginning of the test site. Each data collection location was denoted with white marking paint along the shoulder of the driving lane in order to ensure that all future readings would be collected from the same location.

Retroreflectivity readings and visual assessments were collected on a periodic basis through the spring of 2007 utilizing an LTL 2000 retroreflectometer which employs 30 meter geometry. Photographic documentation was also gathered at individual test site locations during each field visit. Figures 5 through 8 show the condition of the yellow and white edge lines at test site 5, located at MM 0.950 WB, on July 30, 2003, 49 days following application, and at a recent site visit on May 30, 2007, four years following application, along with wear ratings of the markings. All retroreflectivity and durability readings were recorded onto the appropriate field forms and then compiled into a dedicated spreadsheet. The data collection process was carried out year round, including winter months when the ambient air temperature fell below the minimum temperature specified within the ASTM testing procedures of 40^{o}F. However, care was taken to maintain the testing equipment above the minimum specification during travel and between test sites. Where warranted, the pavement markings were cleaned with a mixture of water and windshield washer fluid to remove any salt, dirt or other debris and then thoroughly dried prior to data collection in accordance with the “Protocol for the Cleaning of Line Striping to Test for Retroreflectivity.” A copy of the protocol is provided in Appendix A.

Figure 5 – Test Site 5 White Edge Line
July 30, 2003, Wear Rating = 10

Figure 6 – Test Site 5 White Edge Line
May 30, 2007, Wear Rating = 4

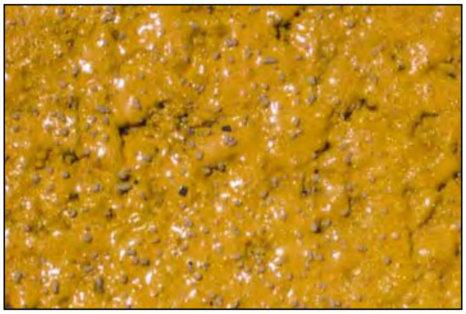

Figure 7 – Test Site 5 Yellow Edge Line
July 30, 2003, Wear Rating = 10

Figure 8 – Test Site 5 Yellow Edge Line
May 30, 2007, Wear Rating = 5

The first site visit was conducted on, July 9th, 2003, nine days following application of the polyurea pavement markings. All pavement markings were found to be intact. A summary of initial retroreflectivity readings are provided below in Table 2. Please note that all pavement markings, both recessed and surface applied, were found to be in compliance with ASTM 6359, "Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments" which requires a minimum retroreflectivity of 250 mcdl for white markings and 175 mcdl for yellow markings within 14 days of application.

Burlington-South Burlington: Initial Retroreflectivity Readings Experimental Materials (mcdl/m2/lux)					
Material	**Test Site**	**Mile Marker**	**White Edge Line**	**White Skip Line**	**Yellow Edge Line**
Recessed 3M LPM 1200	1	0.2 EB	909	906	796
Recessed 3M LPM 1200	2	0.6 EB	913	881	798
Recessed 3M LPM 1200	7	0.7 WB	892	1048	746
Recessed 3M LPM 1200	8	0.45 WB	982	916	787
		Average:	**924**	**938**	**782**
		Standard Deviation:	**40**	**75**	**24**
Surface Applied 3M LPM 1200	3	0.8 EB	1003	1028	855
Surface Applied 3M LPM 1200	4	1.20 EB	987	981	842
Surface Applied 3M LPM 1200	5	0.95 WB	750	944	826
Surface Applied 3M LPM 1200	6	0.85 WB	959	915	809
		Average:	**925**	**967**	**833**
		Standard Deviation:	**118**	**49**	**20**

Table 2 – Initial Retroreflectivity Readings

In examining the data sets, initial results from both the recessed and surface applied pavement markings are promising and were found to be well above minimum standards. Specifically, the retroreflectivity of the markings for both methods were found to be 5 to 9 times an order of magnitude greater than the minimum specification and can most likely be attributed to the microcrystalline ceramic elements applied to the marking binder. The average retroreflectivity readings were fairly consistent in all sampling locations as further supported by the relatively low standard deviation when compared to the average retroreflectivity readings.

In addition to verifying initial retroreflectivity compliance with ASTM D 6359, all markings were monitored for performance over time. The service lives of pavement markings were used to compare durability and degradation rates to a predefined benchmark in order to evaluate and determine life cycle costs. The analysis of pavement markings was performed by comparing retroreflectivity readings to the amount of time the markings displayed acceptable retroreflectivity. To date, the Federal Highway Administration, or FHWA, and other federal and state authorities have not established a minimum requirement for retroreflectivity of pavement markings. However, FHWA has compiled recommended retroreflectivity guidelines for white and yellow pavement markings for different classes of roads as shown in Table 3.

1998 FHWA Research-Recommended Pavement Marking Values			
Type	**Non-Frwy**	**Non-Frwy**	**Freeway**
Option 1	<= 40 mph	>= 45 mph	>= 55 mph
Option 2	<= 40 mph	>= 45 mph	>= 60 mph, >10K ADT
Option 3	<= 40 mph	45-55 mph	>= 60 mph
White	85	100	150
Yellow	55	65	100

Table 3 – FHWA Recommendations

WHITE EDGE LINES

As recommended by the FHWA, a minimum recommended retroreflectivity of 150 mcdl was selected as the benchmark for evaluating white interstate markings. Table 4, as shown below, contains a summary of average reflectance for each composition of white edge lines. Please note that any readings below 150 mcdl are highlighted in red.

Burlington-South Burlington: White Edge Retroreflectivity Averages, (mcdl/m²/lux)		
Date of Collection	**Recessed**	**Surface Applied**
07/09/2003	924	925
11/06/2003	739	772
04/07/2004	296	131
05/06/2004	259	131
08/04/2004	391	137
10/18/2004	314	125
05/05/2005	162	77
07/19/2005	126	65
09/28/2005	172	71
05/10/2006	116	47
03/29/2007	77	34
05/30/2007	87	40
07/12/2007	89	44

Table 4 – Retroreflectivity Summary for White Edge Line

As anticipated, a significant drop in retroreflectivity, 711 mcdl on average, is evident across all markings following the first winter season when comparing the result from July 2003 to those of April 2004. This is most likely attributed to shearing effects resulting from winter maintenance practices. The surface applied markings displayed the largest loss with an average drop of 794 mcdl to a reading of 131 mcdl over the first winter compared to an average drop of only 628 mcdl to a reading of 296 mcdl for the recessed markings. This provides evidence to suggest that recessing the markings provided some protection. Once again, it is important to consider the size of the ceramic elements which are quite large in comparison to standard glass beads. While they provide a much greater initial retroreflectivity, roughly 1000 mcdl on average as compared to standard glass beads at 400 mcdl on average, they may be more prone to become dislodged due to their size. Wear readings collected during this timeframe were found to be around 8 for the white edge lines.

This pattern continued throughout subsequent data collection events, with the surface applied pavement markings dropping off at a much higher rate than the recessed markings. As expected, the readings rebounded seasonally following winter months and snow plow practices. Between May and August 2004 a rise in readings was noted in both the recessed and surface applied markings. The recessed markings went from a value of 259 mcdl in May 2004 to a value of 391 mcdl in August 2004, and the surface applied markings went from 131 mcdl to 137 mcdl. This is most likely attributed to shearing effects produced by snow plows in the winter months reducing refraction and retroreflectivity. During summer months the beads are subjected to abrasion from vehicle tires, exposing embedded glass beads and increasing retroreflectivity. However, it is unknown how this may affect the ceramic beads. Given the large drop in retroreflectivity following the first winter season, it may be surmised that any protruding elements were dislodged by a snow plow and unable to be fully exposed during summer months.

YELLOW EDGE LINES

A similar analysis was performed on the yellow pavement markings with a minimum acceptable retroreflectivity of 100 mcdl. Table 5 contains a summary of average reflectance for each application method of yellow edge lines. Please note that any readings below 100 mcdl are highlighted in red.

Burlington-South Burlington: Yellow Line Retroreflectivity Averages, (mcdl/m^2/lux)		
Date of Collection	**Recessed**	**Surface Applied**
07/09/2003	782	833
11/06/2003	647	601
04/07/2004	451	151
05/06/2004	563	118
08/04/2004	534	148
10/18/2004	551	142
05/05/2005	420	118
07/19/2005	421	111
09/28/2005	493	110
05/10/2006	363	104
03/29/2007	318	75
05/30/2007	387	99
07/12/2007	347	85

Table 5 – Retroreflectivity Summary for Yellow Edge Lines

A significant drop in retroreflectivity, 507 mcdl on average, is evident across all yellow markings following the first winter season with consideration to the results from July 2003 to those of April 2004. Once again, the surface applied yellow LPM markings displayed the highest response to plowing with an average loss in retroreflectivity of 628 mcdl. The recessed markings displayed an average loss of 331 mcdl, almost 50% less than the surface applied markings. Results collected the following April in 2004 indicated an average retroreflectivity of 151 and 451 mcdl for the surface applied and recessed markings, respectively. These results are somewhat surprising as white markings generally display higher retroreflectivity as compared to yellow markings due to their respective pigments. In both cases, the yellow markings displayed a higher retroreflectivity. It should be noted that this roadway section is relatively straight whereas a curved alignment could generate interferences in the data sets.

This pattern continued throughout subsequent data collection events, with a greater loss in retroreflectivity of the surface applied pavement markings as compared to the recessed pavement markings. As with the white edge lines, the summer rebound of the retroreflectivity readings can be noted in this data set, with values increasing between spring and summer collection events. Wear readings collected in October 2004 showed a drop to between 7 and 8 for the recessed markings and around 5 for the surface applied markings. Overall, the yellow marking displayed a much greater reflectance than their counterpart, the white markings. This is very counterintuitive and may have been due to the proximity of physical objects, such as guardrail, to the roadway. However, guardrail is located on both sides of the road in varying locations. It also could be due to the higher traffic volume in the right travel lane, resulting in more vehicles driving over the white edge line. This would cause more of the reflective microcrystalline beads to be worn off of the white edge lines than from the yellow edge lines. The microcrystalline beads provide a majority of the retroreflectivity for the markings, so this increased wear would cause a large difference in the retroreflectivity readings.

SERVICE LIFE

Service life estimates for the white edge line pavement markings could not be determined from Table 4 due to the irregular time frame between data collection events. Therefore, a scatter plot of the data was generated in order to establish the approximate amount of elapsed time before retroreflectivity values fell below 150 mcdl, as shown in Figure 9.

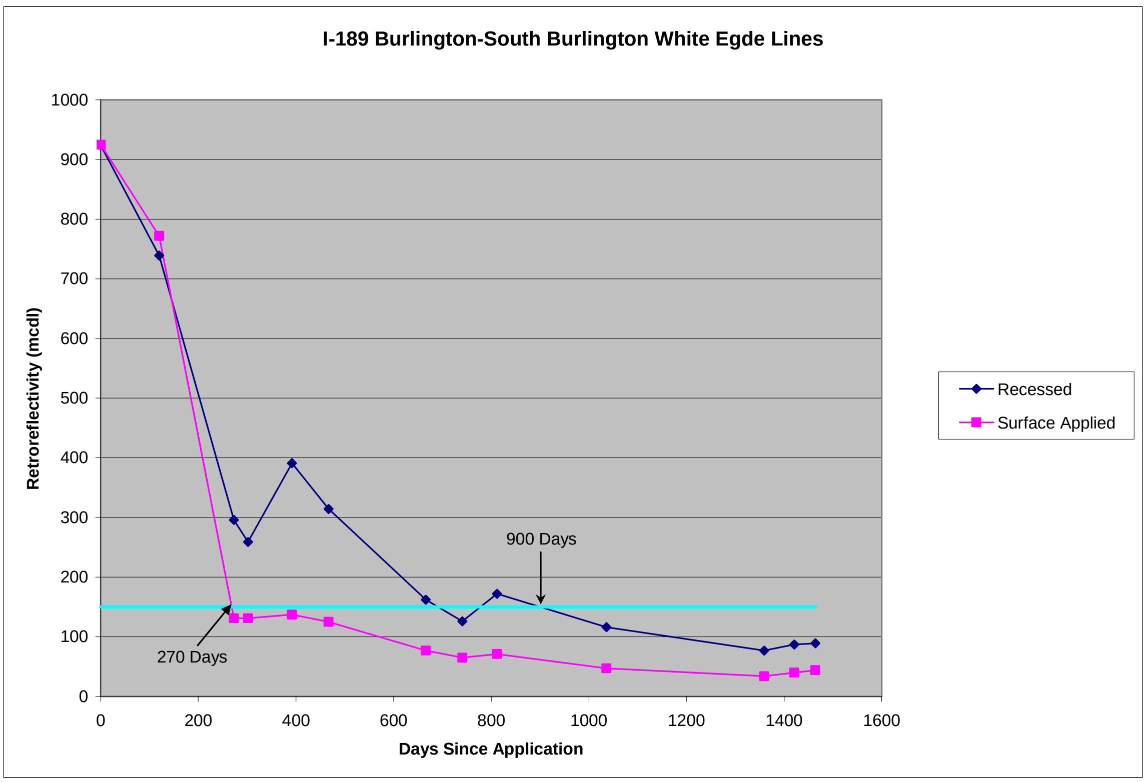

Figure 9 – Service Life of White Edge Lines

Estimated service lives for the white edge line pavement markings are 270 days for the surface applied markings and 900 days for the recessed markings.

A similar analysis was completed for the yellow edge lines to establish the estimated amount of time before the retroreflectivity values fell below 100 mcdl, as shown in Figure 10.

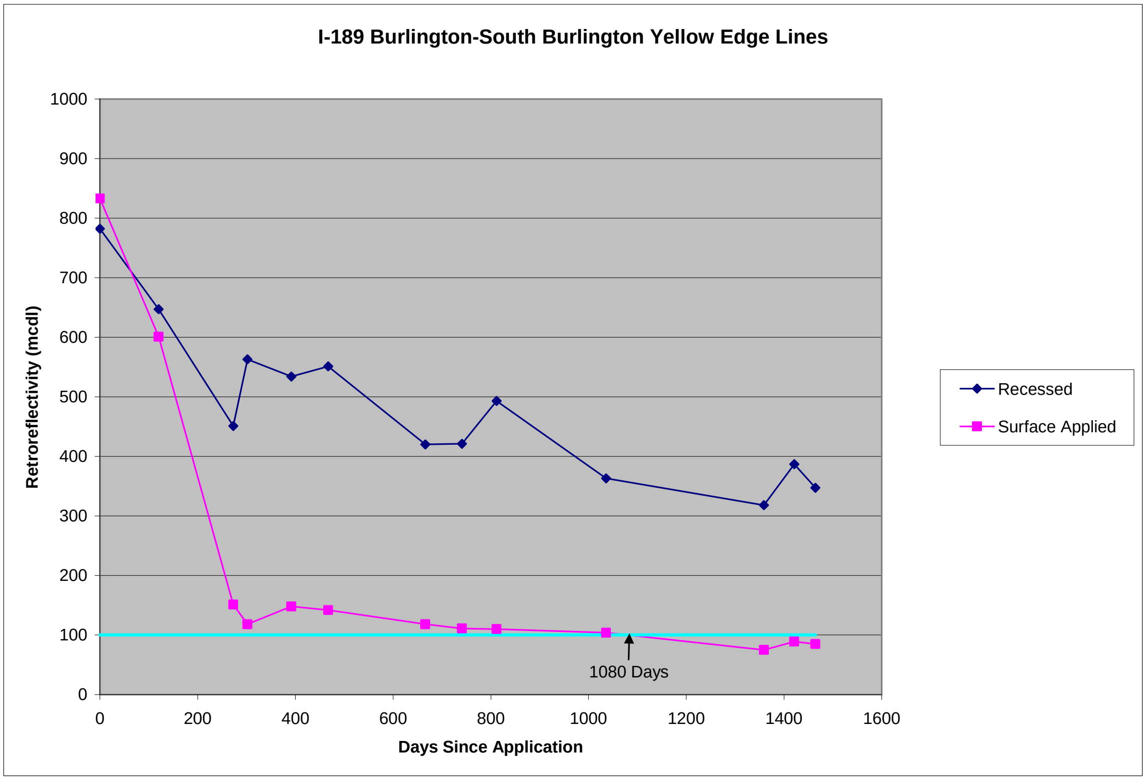

Figure 10 – Service Life of Yellow Edge Lines

Based on the readings gathered so far, the recessed yellow edge lines have not yet reached the end of service life, as they were still well above 100 mcdl at the time of the last data collection. Therefore a service life estimate could not be performed. The readings for the surface applied markings fall below 100 mcdl after 1080 days, indicating that at this point the end of service life has been reached.

COST ANALYSIS

All costs for the application of the various pavement markings were paid for as part of the Burlington – South Burlington construction project. The application cost was $1.16/LF for the surface applied markings and $1.67/LF for the recessed markings. The cost per month for each application method was calculated by dividing the total cost of the application per linear foot by the estimated service life in months. As the recessed yellow edge lines have not yet reached the end of service life, a cost analysis could only be completed for the white edge lines. The cost analysis for white edge lines is shown in Table 6.

Burlington-South Burlington				
Cost Analysis for White Edge Lines				
	Elapsed Time		**Cost**	**Cost/Month**
Marking Type	**Days**	**Months**	**($/LF)**	
Surface Applied	270	9	1.16	$0.13
Recessed	900	30	1.67	$0.06

Table 6 - Cost Analysis (White Edge Lines)

The recessed pavement markings were found to have the lowest material cost per month, as well as a service life almost three times longer than that of the surface applied markings. Overall this method appears to be the most cost effective in consideration to the cost per month and duration of service life.

SUMMARY

In an effort to prolong the service life of pavement markings, the Vermont Agency of Transportation (VTrans) engaged in a study to examine the effectiveness of recessing pavement markings, otherwise known as the application of markings into a groove in the pavement as in theory this should protect the pavement marking binder and reflective elements from damage produced by winter maintenance practices and abrasion from tires. Following the placement of the control section, or surface applied markings, and experimental section, or recessed polyurea markings, data collection was conducted using uniform methods, collected on the same days and weather conditions and without favoring one type of application over another. After only 0.75 years of service, all surface applied white edge lines on this project had fallen below the FHWA Recommendations, while it took nearly 2.14 years of service for the recessed white edge lines to fall below FHWA Recommendation. This trend was also displayed with the yellow edge lines, although in general they had much longer surface lives than the white edge lines. The yellow surface applied markings provided almost three years of service before falling below FHWA Recommendations, while the recessed markings were still well above the FHWA Recommendations after the last observation, approximately four years after installation. The reason for the longer service life of the yellow edge lines could be due to higher traffic volume in the right lane causing increased wear on the white edge lines and other physical objects, such as adjacent guard rail.

The data evidenced a large drop in readings on all materials following the first winter season, although the drop was not as significant in the recessed markings as it was in the surface applied markings. Due to the shearing effects produced by winter maintenance practices, the larger diameter beads, or ceramic elements, may have become dislodged or shaved off, resulting in a great loss of retroreflectivity. According to our analysis, by recessing the pavement markings, the reflective glass beads and elements were protected from the snow plows resulting in higher retroreflectivity readings after winter months as compared to surface applied markings. Generally it can be stated that recessing pavement markings can be considered beneficial for extending the performance of the pavement marking. In addition, recessing markings appears to be highly cost effective in terms of service life. Other incidental items that were not considered in the cost analysis pertains to restriping efforts as recessing the markings provides an extended service life in comparison to surface applied markings. This life extension increases the time duration until restriping is needed, decreasing future mobilization and material costs.

Recessing polyurea markings is recommended along limited access highways and in high AADT locations.

REFERENCES

American Association of State Highway and Transportation Officials' (AASHTO). "Glass Beads Used in Traffic Paint." *Standard Specifications for Transportation Materials and Methods of Sampling and Testing* June 2004: M247-1 – M247-3.

American Society for Testing and Materials (ASTM). "D 711, Test Method for No-Pick-Up Time of Traffic Paint." *Volume 06.02 Paint-Products and Applications; Protective Coatings; Pipeline Coatings* 2007: 20 – 21.

American Society for Testing and Materials (ASTM). "D 913-03, Evaluating Degree of Resistance to Wear of Traffic Paint." *Volume 06.02 Paint-Products and Applications; Protective Coatings; Pipeline Coatings* 2007: 29 – 31.

American Society for Testing and Materials (ASTM). "E 1710-97, Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer." *Volume 06.01 Paint – Tests for Chemical, Physical, and Optical Properties; Appearance* 2007: 1086 – 1091.

American Society for Testing and Materials (ASTM). "D 6359, Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments." *Volume 04.03 Road and Paving Materials; Vehicle-Pavement Systems* 2006: 712 – 714.

Ashworth, Lindsay. *Work Plan for Category II Experimental Project, 3M Stamark Polyurea, Liquid Pavement Marking Series 1200 in Grooved Pavement Surfaces, Work Plan 2002-R-1*. Vermont Agency of Transportation, April 2002.

Federal Highway Administration. "Section 718, Traffic Signing and Marking Material." *Standard Specification for Construction of Roads and Bridges on Federal Highway Projects, FP-03* 2003: 678.

Outcalt, William. *Recessed Striping in Concrete Pavement*. Colorado Department of Transportation, August 2004. http://www.dot.state.co.us/publications/PDFFiles/Recessedstriping.pdf

Appendix A

Protocol for the Cleaning of Line Striping to Test for Retroreflectivity.

Equipment needed:

1. Windshield washer fluid
2. Water
3. Two liquid dispensers
4. Towels or rags
5. Squeeze mop and/or sponges
6. Gas powered leaf blower

PROCEDURE

Step 1 – Mix ½ water and ½ windshield washer fluid into the first liquid dispenser. The other liquid dispenser should have water only.

Step 2 – Thoroughly clean the lines with the windshield washer fluid mixture using the dispenser to spray away as much salt, dirt and other debris as possible.

Step 3 – Thoroughly clean the lines with the water dispenser, spraying away the windshield washer mixture. * Note: Make sure you start at the highest point of the surface to be cleaned and wash down to the lowest point.

Step 4 – Using the squeeze mop and sponges clean away as much excess water as possible. Wipe the line surfaces with a towel or rag to get the surfaces as dry as possible.

Step 5 – Utilizing a gas powered leaf blower or similar device blow the lines off until completely dry.

Step 6 – Begin Retroreflectometer Testing.