REPORT 2012 - 04

VERMONT AGENCY OF TRANSPORTATION

Materials & Research Section
Research Report

EVALUATION OF 3M^{TM} STAMARK ALL WEATHER LIQUID PAVEMENT MARKING SERIES 1400

Report 2012 – 04

May 16, 2012

EVALUATION OF 3M™ STAMARK ALL WEATHER LIQUID PAVEMENT MARKING SERIES 1400

Report 2012 – 04

MAY, 2012

Reporting on Work Plan 2008-R-03

STATE OF VERMONT
AGENCY OF TRANSPORTATION

MATERIAL & RESEARCH SECTION

BRIAN R. SEARLES, SECRETARY OF TRANSPORTATION
RICHARD M. TETREAULT, P.E., DIRECTOR OF PROGRAM DEVELOPMENT
WILLIAM E. AHEARN, P.E., MATERIALS & RESEARCH

Prepared By:

Jason P. Tremblay, M.S.

Reviewed By:

William E. Ahearn, P.E.,
Materials & Research Engineer

Date: May 16, 2012

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
2012-04	- - -	- - -

4. Title and Subtitle Evaluation of 3M™ Stamark All Weather Liquid Pavement Marking Series 1400	5. Report Date MAY, 2012 6. Performing Organization Code
7. Author(s) Jason P. Tremblay, M.S.	8. Performing Organization Report No. 2012-04
9. Performing Organization Name and Address Vermont Agency of Transportation Materials and Research Section 1 National Life Drive National Life Building Montpelier, VT 05633-5001	10. Work Unit No. 11. Contract or Grant No. 2008-R-03
12. Sponsoring Agency Name and Address Federal Highway Administration Division Office Federal Building Montpelier, VT 05602	13. Type of Report and Period Covered Final (2008-2010) 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

In an effort to analyze the effectiveness of newly developed reflective elements with wet night properties, the Agency recessed 3M™ Stamark All Weather Liquid pavement marking LPM 1400 on a portion of the Richmond – South Burlington project, IM 089-2(39).

It was hoped that the LPM 1400 products would be less vulnerable to winter maintenance practices. The yellow edgeline markings, for both products, upheld satisfactorily, remaining above the recommended minimums following two winter seasons. Unfortunately, with respect to retroreflectivity, this just was not the case for the white skip markings, most likely due to the centerline location, where markings are subject to more traffic changing lanes and a greater number of plowing events (typically, the centerline is hit twice, when each lane is plowed). The durability levels of the markings could be considered satisfactory, as many of the markings remain mostly intact and visible under lit conditions. Based on these findings, 3M™ All Weather Liquid Pavement Marking 1400 would be recommended for future interstate recessed markings.

17. Key Words	18. Distribution Statement
Liquid Pavement Marking, LPM, LPM 1400 polyurea	No Restrictions.

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

Form DOT F1700.7 (8-72) **Reproduction of completed pages authorized**

Table of Contents

1. Introduction

It has become common practice by the Vermont Agency of Transportation to recess polyurea markings on interstate rehabilitation projects. Recessing includes the removal of a small portion of the surface of the wearing course prior to the application of permanent markings. While studies have shown that recessing successfully extends the service life of traffic markings by protecting them from wear, there have been several concerns about the effectiveness of these markings under wet conditions. During rain events, a film of water collects over the marking materials causing a change in the indices of refraction between the optical elements and surrounding medium thereby reducing retroreflective properties, or luminance. Feedback from drivers concurs as they report difficultly seeing the marking at night during rain events. As pavement markings provide an important means of communication for all roadway users, they must be capable of conveying information during inclement weather. To address this concern, pavement marking manufacturers have developed innovative traffic markings with wet reflective properties.

According to product literature, 3M™ has created "All Weather Elements," microcrystalline ceramic beads embedded on a center core to provide optimal performance in both wet and dry conditions. Reportedly, the elements are visible dry, during a rainfall and after rainfall, providing the motorist visibility in all weather conditions. 3M™ scientists found that beads with a 2.4 refractive index compensate for the refractive properties of water, making them ideal for reflecting light back to its source under wet conditions[1].

In an effort to analyze the effectiveness of newly developed reflective elements with wet night properties, the Agency recessed 3M™ Stamark All Weather Liquid pavement marking LPM 1400 on a portion of the Richmond – South Burlington project, IM 089-2(39). The following final report assesses the overall performance of these markings in terms of durability and retroreflectivity. 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.

2. Project Details

In association with a federally approved work plan, 2008-R-3[2], LPM 1400was to be applied to a portion the Richmond – South Burlington project, IM 089-2(39). This project, in its entirety, was located along I-89 between mile marker (MM) 78.990 and MM 87.397. According to the project plans, work to be performed included cold planning and resurfacing of the northbound travel lanes, shoulders, and interchange 12,

[1] "*3M™ All Weather Elements Product Bulletin*", 3M™ Traffic Safety Systems Division, January 2010.
[2] Kipp, Wendy, "*Work Plan for Research Investigation: 3M™ Stamark High Performance Wet Reflective Tape Series 380WR ES and 3M™ Stamark All Weather Liquid pavement marking (LPM) Series 1400, Work Plan No. 2008-R-3*", Vermont Agency of Transportation, 2008.

new pavement markings, guardrail improvements and other incidental items. The average annual daily traffic (AADT) is reported to be 26,900 at this location (for both barrels total), a relatively high AADT for Vermont.

The prime contractor for the project, Pike Industries Inc., was responsible for all paving activities, and the subcontractor, L&D Traffic Markings Inc. of Berlin, VT, was responsible for all pavement markings. As specified under the original contract plan, polyurea markings were to be applied throughout the limits of the project (originally the markings were to be LPM 1200). L&D along with the manufacturer, 3M™ of St. Paul, Minnesota, through the general contractor, offered to exchange the project specified traffic markings. A 330 lb tote of 3M™ Stamark All Weather Liquid pavement marking (LPM 1400) replaced a 330 lb tote of 3M™ Stamark Liquid pavement marking (LPM 1200) along the edge line between MM 80.69-MM 82.99. All other parameters and application methods remained unchanged, with LPM 1200 still being applied to the remainder of the project. This means that the recess depth, application thickness and applied bead rate was the same as per the standard LPM 1200. It is important to note that the manufacturer recommended an application thickness of 20 to 22 mils rather than a thickness of 18 to 22 mils for the standard polyurea markings.

3. Product Details

According to the manufacturer, 3M™ of St. Paul, Minnesota, All Weather Liquid Pavement Marking Series 1400 (LPM 1400) is designed for use on roadways and highways primarily as long line pavement markings. The marking is a two-component, 100% solid polyurea coating material that cures rapidly to hardness after application. Reflectivity is provided by a combination of specially treated reflective elements and glass beads. The reflective elements consist of microcrystalline ceramic beads embedded on a center core to provide optimal performance in both wet and dry conditions. Reportedly, the elements are visible dry, during a rainfall and after rainfall, and provide the motorist visibility in all weather conditions.

Several application conditions must be met prior to installation. These include moisture conditions, air temperature, and numerous surface preparations. The pavement must be dry and moisture free when applied and the road and air temperatures must be above 40^oF during application. Prior to applying the markings, the contractor must remove any remaining existing markings to expose a minimum of 80% of the pavement surface. All dirt, sand, dust, oil, grease, and any other contaminants must be removed, and the engineer and/or contractor should determine further restrictions and requirements of weather and pavement conditions necessary to meet all other application specifications and produce markings that perform satisfactory to the engineer.

LPM 1400 markings applied for this project contain both 3M™ Series 50P and 70P all weather elements. Series 50P (the P denoting use for polyurea markings) provide dry retroreflectance while series 70P provide the wet retroreflectance. Table 1 below displays the typical initial retroreflectivity values that could be expected with each element type, according to product literature[3].

Table 1. Typical retroreflectivity values of elements, in mcd/m²/lx.

Reflectivity Property	Color	Series 70	Series 50
Dry Average	White	625	900
	Yellow	470	700
Wet Recovery Average	White	440	345
	Yellow	345	280
Wet Continuous Average	White	150	125
	Yellow	125	90

The reflective media shall be made up of reflective elements and glass beads for drop-on application shall be a blend of 60% sinkers and 40% floaters of AASHTO M 247-81 “Standard Specification for Glass Beads Used in Traffic Paints” Type I gradation 1.5 index glass beads[4]. According to ASTM D1155 “Standard Test Method for Roundness of Glass Spheres”[5], the glass beads must have a minimum of 70% Rounds. Crush resistance shall be measured according to the procedures of ASTM D1213 “Test Method for Crushing Resistance of Glass Spheres”[6] and shall be a minimum of 30 pounds retained on US #40 mesh.

The control pavement marking for this project was 3M™ Stamark Liquid Pavement Marking (LPM) 1200, a polyurea material. This material is the standard marking that was used to restripe the interstate. According to the product data sheets it is initially three times brighter than conventional markings and incorporates a new highly reflective element made of microcrystalline ceramic beads.

4. Installation

The 3M™ All Weather Liquid Pavement Marking (LPM) was applied to the Richmond – South Burlington project, IM 089-2(39), located along I-89 between mile marker (MM) 81.50 and MM 83.50, with the remainder of the project being the LPM 1200 control marking. Experimental markings were used for the yellow edge line and white skip lines within the experimental section only; white edge lines were LPM 1200 throughout.

Bituminous pavement (Superpave type IIIS wearing course) for this section of the road was placed between Wednesday, September 3rd and Tuesday, September 9th, 2008.

[3] “*3MTM All Weather Liquid Pavement Marking Series 1400*”, 3MTM Traffic Safety Systems Division, October 2009.

[4] AASHTO M 247-81 “*Standard Specification for Glass Beads Used in Traffic Paints*” Type I gradation 1.5 index glass beads, Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 27th Edition 2007.

[5] ASTM D1155 “*Standard Test Method for Roundness of Glass Spheres*”, ASTM International, West Conshohocken, PA, <www.astm.org>.

[6] ASTM D1213 “*Test Method for Crushing Resistance of Glass Spheres*”, ASTM International, West Conshohocken, PA, <www.astm.org>.

Recessing for the LPM markings occurred on Thursday, October 9th, 2008 with night grinding. Application of the markings occurred on Saturday October 11th. Recess depths were to the manufacturer recommended depth of 40 mils. Unfortunately it is unknown as to whether or not the recesses were cleaned out prior to application of the markings as is recommended. Research personnel were onsite for the marking placement. During marking application pavement and line temperature readings were taken to verify that the pavement was above the minimum required application temperature of 40°F. A total of eighteen temperatures were taken at various locations and times. The average pavement temperature was 51.4°F with a range of 45°F to 56°F and a polyurea average temperature of 53.9°F and a range of 47°F to 59°F. As noted earlier, application of these markings can occur down to a substrate temperature of 40°F, therefore the application temperatures were within manufacturer recommendations. Markings were placed at the manufacturer recommended thickness of 22 to 25 mils.

5. Surveillance and Testing

A total of nine test sites were established throughout the length of the project in order to collect 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"[7], and durability, in accordance with ASTM D 913-03, "Evaluating Degree of Resistance to Wear of Traffic Paint."[8] Six test sites were within the experimental marking section and three within the control. The test site locations are as shown in Table 2. Each test site was established in an area with good sight distance on a straight away. Test sites 1 through 7 consisted of a total length of 40 feet with data collection conducted at 10 foot intervals along the yellow edge line starting from the beginning of the test site. For test sites Skip 1 and 2, every fourth white skip line was measured, for a total of 16 measurements in the experimental sections and six in the control.

Retroreflectivity readings and visual assessments were collected utilizing an LTL 2000 Retroreflectometer, which employs 30-meter geometry. Photographic documentation was also gathered at individual test site locations during each field visit. All retroreflectivity and durability readings were recorded onto the appropriate field forms and then compiled into a dedicated spreadsheet.

[7] ASTM E 1710-97, "Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer," ASTM International, West Conshohocken, PA, <www.astm.org>.
[8] ASTM D 913-03, "Evaluating Degree of Resistance to Wear of Traffic Paint," ASTM International, West Conshohocken, PA, <www.astm.org>.

Table 2. Locations of the nine test sites.

Test Site	Mile Marker	Product
1	81.5	LPM 1400
2	81.7	LPM 1400
3	81.9	LPM 1400
4	82.1	LPM 1400
5	82.3	LPM 1400
6	83.2	LPM 1200
7	83.5	LPM 1200
Skip 1	81.5	LPM 1400
Skip 2	83.5	LPM 1200

The initial site visit was conducted on October 17th, 2009, 6 days following installation for both the LPM 1400 and 1200. All pavement markings were found to be intact as shown in Figure 1. A summary of initial retroreflectivity is provided within Tables 4 and 5 below, along with all averaged values for the duration of the evaluation. Values are averaged over all readings per test site for each marking type and color. A complete list of all readings can be found in Appendix A. Both the experimental and control traffic markings were found to be in compliance with ASTM D 6359, "Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instrument"[9] which requires a minimum retroreflectivity of 250 mcd/m^2/lx for white markings and 175 mcd/m^2/lx for yellow markings within 14 days of application.

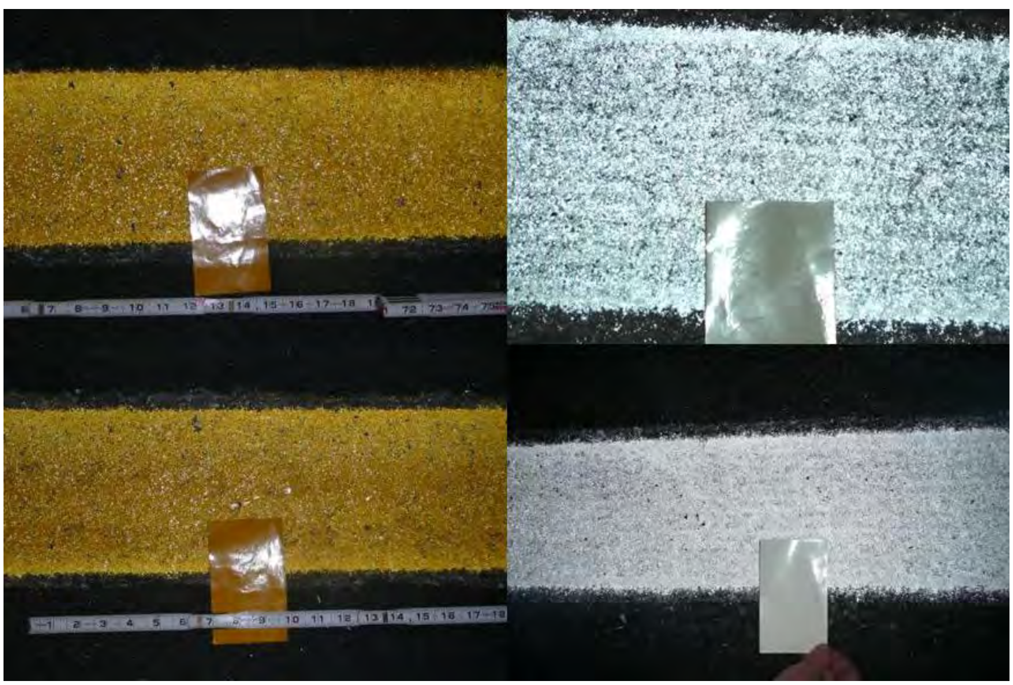

Figure 1. Comparison of marking appearance during the initial site visit; LPM 1400 on the top and LPM 1200 on the bottom.

[9] ASTM D 6359-99, "Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments," ASTM International, West Conshohocken, PA, <www.astm.org>.

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. 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 marking for different classes of roads as shown in Table 3. As I-89 is classified as a freeway with a posted speed limit of 65 mph, the recommended minimum retroreflectivity for white markings is 150 mcd/m^2/lx and 100 mcd/m^2/lx for the yellow markings. Any readings that fall below the FHWA recommendations are colored red in the retroreflectivity tables.

Table 3. FHWA recommended retroreflectivity minimums.

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

5.1. LPM 1400 and LPM 1200 Retroreflectivity

Tables 4 and 5, as shown below, contains a summary of average reflectance for each marking type and each color. The FHWA recommendation of 150 mcd/m^2/lx for minimum retroreflectivity was selected as a benchmark for the lines. Please note that any readings below the recommended value are colored red. All of the data summary tables display averages of all readings taken for each test site, along with the associated overall averages for each date. Individual readings from each testing date can be found in Appendix A.

Table 4. Average retroreflectivity values and associated standard deviations of yellow markings. Values below the FHWA recommended minimums are in red.

Site Visit	Days Since Application	LPM 1400		LPM 1200	
		Avg. Retro	Standard Deviation	Avg. Retro	Standard Deviation
10/17/08	6	465	86	369	22
5/4/09	205	310	47	303	21
7/28/09	290	299	42	286	47
9/16/09	339	314	45	299	24
12/2/09	416	150	21	**148**	5
2/2/10	478	**17**	8	**11**	9
4/13/10	548	257	33	243	26

Table 5. Average retroreflectivity values and associated standard deviations of white markings. Values below the FHWA recommended minimums are in red.

Site Visit	Days Since Application	LPM 1400		LPM 1200	
		Avg. Retro	Standard Deviation	Avg. Retro	Standard Deviation
10/17/08	6	636	103	720	76
5/4/09	205	**92**	15	**137**	23
7/28/09	290	**99**	19	**131**	12
9/16/09	339	**95**	17	**139**	13
12/2/09	416	**48**	11	**69**	13
2/2/10	478	**31**	5	**18**	3
4/13/10	548	**64**	16	**91**	7

Initial averaged retroreflectivity values for all markings were well above the required 250 mcd/m^2/lx. When reviewing the data in the tables, it is important to note that the site visit conducted on February 2nd, 2010 occurred during a time of considerable snow having collected on the shoulders from plowing activities and also during a time with a high level of road salt present on the road; two test sites could not be evaluated due to the snow. These factors are believed to have led to the very low values that were recorded on this date and are not considered representative of the true nature of the markings at that time. It is, in general, clear to see the impact that taking reading during winter months (i.e. presence of road salt and other debris) has on the values, as they are lower than during other months; once spring rains come, retroreflectivity values have a tendency to rebound somewhat.

Initial readings for LPM 1400 markings were found to be 26% higher than the 1200 markings. Values for both products fell in a similar manner for yellow markings, slowly degrading over the year and a half study life. As of the final site visit, both yellow markings were still above recommended minimums, with LPM 1400 having fallen 45% from initial and LPM 1200 by 34%. All told, LPM 1400 remained 6% higher than LPM 1200, 257 to 243 mcd/m^2/lx.

Initial readings for LPM 1400 markings were found to be 13% lower than the 1200 markings. Conversely to the yellow edgeline, white skip line markings fell drastically following the initial site visit, never measuring above FHWA recommended minimums again. Both markings retro values fell approximately 90% as of the final site visit, with LPM 1200 values remaining 42% higher than the LPM 1400. This is a misleading percentage, however, as the values of 91 and 64 mcd/m^2/lx, respectively, are very low.

The variability of the data during the initial site visit was much larger for the experimental than the control (with respect to standard deviation), but became fairly consistent through the rest of the evaluation period. As tends to be the case, the variability of the retroreflectivity values decreases as the marking wear and display lower measured values. It should be considered, however, that there were five test sites (25 individual readings) of experimental markings for yellow edgeline compared to two (10 individual readings) for control, and 16 markings tested for experimental white skip lines compared to six for the control.

5.2 Appearance of LPM 1400 Tape and LPM 1200

Another important aspect pavement marking durability is resistance to wear. Line appearance is an importance factor, as the pavement marking substrate provides roadway delineation during daylight hours. Over time pavement markings can fade, crack, pit, and debond from the underlying surface. Any damage may reduce driver awareness, regardless of the retroreflectivity values, as the road boundaries begin to disappear. Therefore, marking appearance was examined during each site visit in accordance with ASTM D 913-03. Appearance was expressed as a number between 0 and 100%, with 0% representing a line that is no longer visible and 100% representing a line in perfect condition. A summary of the appearance of the lines over time is represented by Table 6.

Table 6. Appearance ratings for the different markings during site visits.

Site Visit	Days Since Application	LPM 1400 Yellow	LPM 1200 Yellow	LPM 1400 White Skips	LPM 1200 White Skips
10/17/08	6	100	100	100	100
5/4/09	205	95	95	95	95
7/28/09	290	95	95	95	95
9/16/09	339	95	95	90	95
12/2/09	416	90	90	85	90
2/2/10	478	90	90	85	90
4/13/10	548	85	85	85	85

The values in the table indicate that the appearance and durability of the yellow markings degraded slower than that of the white skip lines. These appearance ratings show that the location of the line is most likely the primary difference in deterioration rather than the type of polyurea and bead used, as they degrade at the same rate by color and location with little noticeable variation between LPM 1200 and LPM 1400. Appearance ratings seem to be on par with other types of markings that have been studied in the past, with two winter plowing seasons inclusive. It was expected that the recessing of the markings would have a more profound effect on maintaining the appearance of the lines than it did, however this stretch of road receives one of the highest AADTs in the state. Figures 1 (previous), 2, and 3 (below) show the condition of the all markings during the initial readings, after one winter, and at the final site visit (two winter's wear). It can be theorized that the white lines deteriorated faster than the yellow lines because the significant amount of lane changing in this stretch of I-89 with the amount of exits and attractions in the area or the effect of increased plowing because of the required overlap of left and right lane maintenance vehicles.

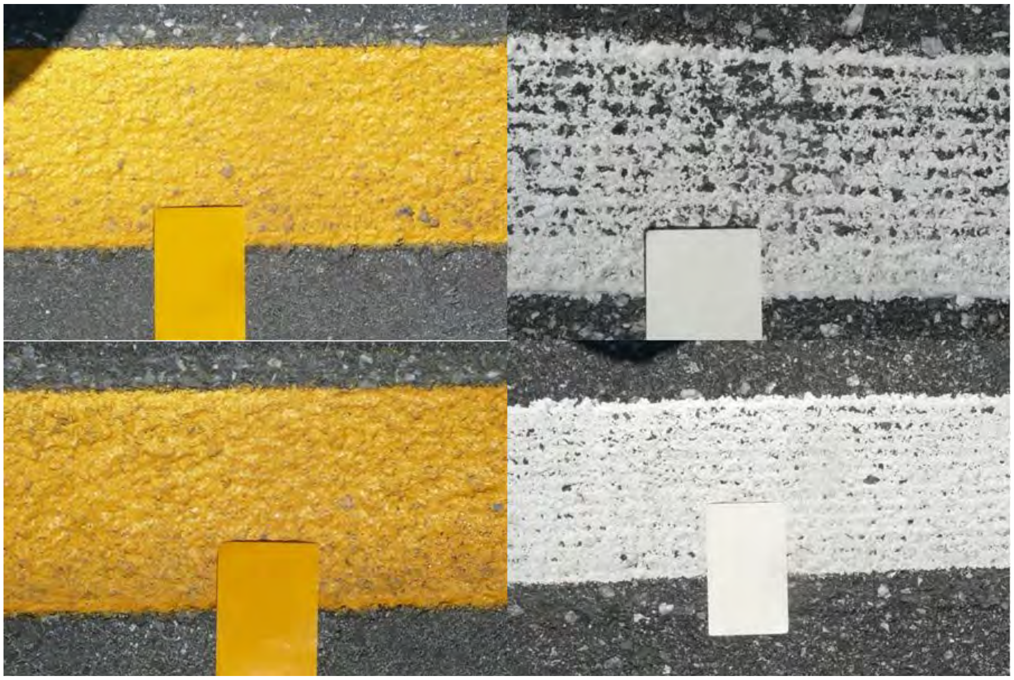
Figure 2. Comparison of marking appearance during a site visit following one winter (July 2009); LPM 1400 on the top and LPM 1200 on the bottom.

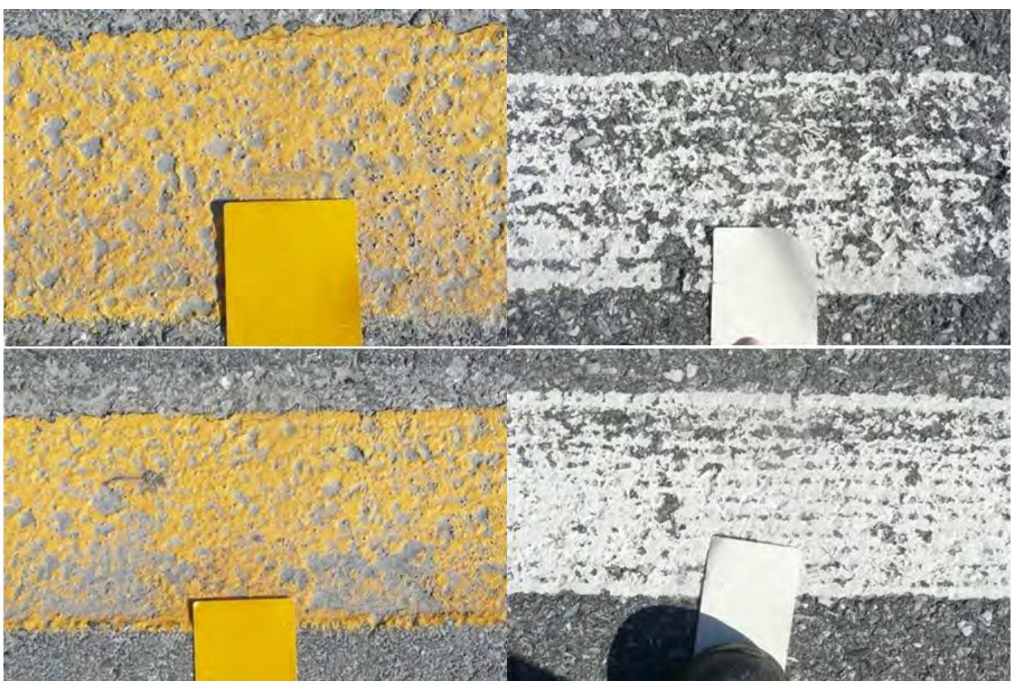
Figure 3. Comparison of marking appearance during the final site visit, following two winters (April 2010); LPM 1400 on the top and LPM 1200 on the bottom.

5.3. Service Life

Service life estimates for the experimental and control markings could not be determined due to the large extent of time 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 and 100 mcd/lx/m2, respectively, as shown in Figures 4 and 5. The model below assumes a linear rate of decay between data collection events.

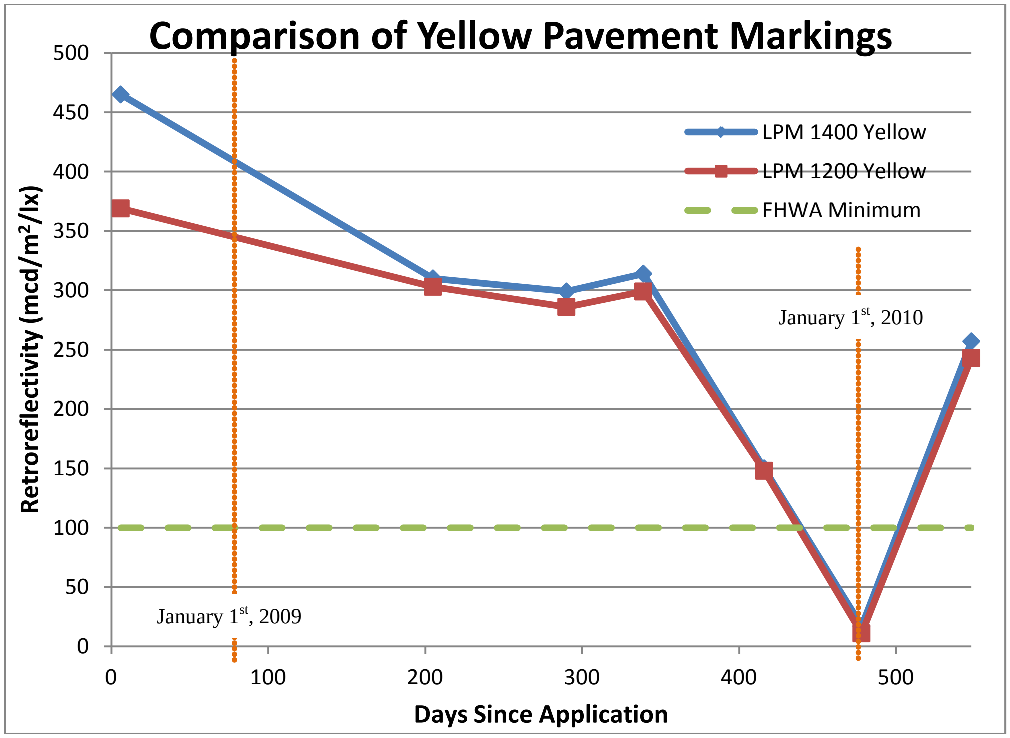

Figure 4. Plot displaying retroreflectivity values versus time for yellow markings.

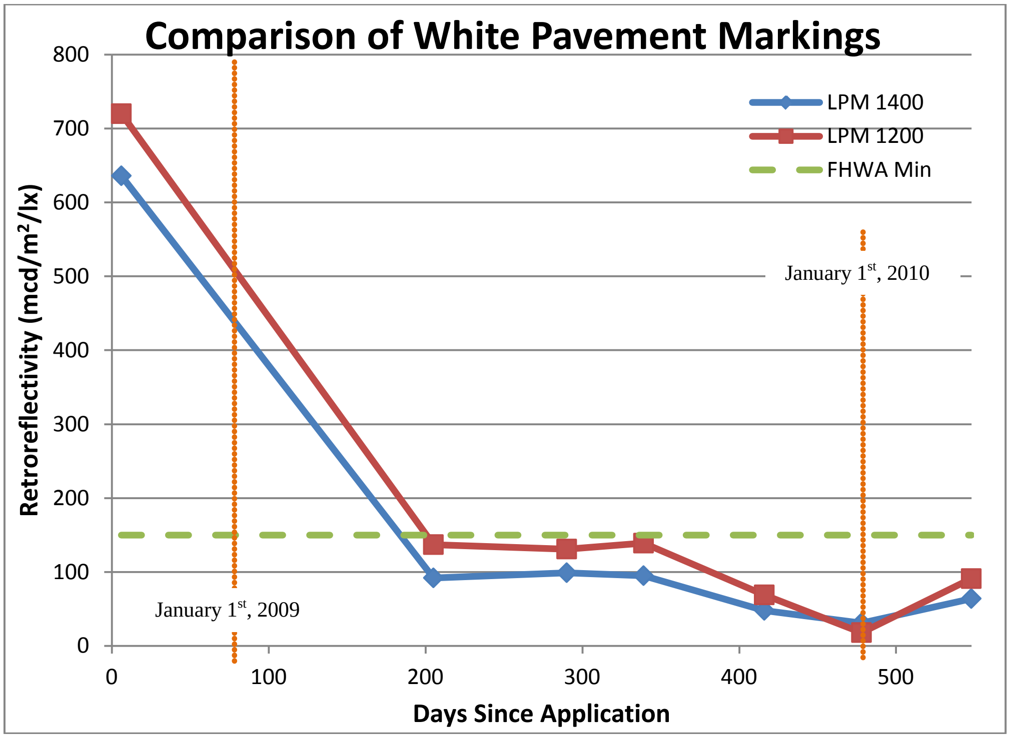

Figure 5. Plot displaying retroreflectivity values versus time for white markings.

The graphical representations clearly display a strong correlation between winter maintenance practices and pavement marking decay for both marking substrates. The effects of the first winter season appear to result in the greatest decay over the monitoring period for the white skip markings, but not as severe for the yellow edgeline on retroreflectivity. The extrapolation of a linear rate of decay is a characteristic of the graphing software. Based on the timing of the readings, winter maintenance practices would have been the most significant contributor to the dramatic reduction. Future research will more closely examine the effect of the residual depth and roughness of the recess on centerline applications.

The yellow edge lines dropped below the recommended minimum of 100 mcd/m^2/lx at approximately the same time, on day 438 for LPM 1200 and day 439 for LPM 1400. This may be misleading, however, as the February 2nd, 2010 site visit occurred within a period of time that had seen snow, cold temperatures, and heavy road salting (brine solution); this may have severely lowered the retroreflectivity values. The subsequent site visit, April 13th, 2010 following a rainy period, showed a rebound in values for the yellow markings, to a level back above the FHWA recommended minimum. Therefore it could be theorized that prior to line restriping in the summer of 2010, the yellow markings for both LPM 1400 and 1200 did not truly fall below the minimums.

Conversely, to the yellow markings, the white LPM 1200 and LPM 1400 both fell below the recommended minimum of 150 mcd/m^2/lx fairly rapidly. Within two weeks of each other, at 201 and 184 days following application, respectively, the white markings were below minimum. While white lines remained below the recommended minimums from this point until the end of the study.

5.4. Cost Analysis

The cost for both the LPM 1400 and 1200 markings, material and installation, were identical. Both materials are applied in the same manner and utilize the same binder material and glass beads. The reflective elements are the only difference in the process and, according to the subcontractor and line applicator L&D Traffic Markings Inc., they have the same cost as well. Approximate costs of the materials are as follows: binder $65 per gallon, glass beads $0.012 per linear foot, and elements $0.058/LF. According to L&D. the total cost to apply LPM 1200 or 1400 polyurea (material, labor, and grooving) is roughly $1.25 per linear foot.

Table 7 provides a cost comparison between the two markings versus their documented service life (or time until retroreflectivity values fell below FHWA recommended minimums). Only white markings are presented in this table, as yellow markings did not fall (and stay) below minimums. Overall, both markings cost the same amount and exhibited virtually the same service life, with LPM 1200 analysis resulting in a less than two-cent cost savings per month per linear foot.

Table 7. Cost analysis summary for both marking types. All costs are in dollars per linear foot.

Material	Service Life* (Months)	Material Cost	Labor and Equip. Cost	Grooving Cost	Total Cost	Cost per Month
LPM 1400	6.1	0.49	0.41	0.34	1.25	0.204
LPM 1200	6.7	0.49	0.41	0.34	1.25	0.186

* Service life is an estimate for white markings only

Another methodology to compare the cost effectiveness of a marking material is to determine its net benefit to the user over its lifespan with consideration to increased retroreflectivity and older drivers. A study conducted by the University of North Carolina at Charlotte concluded, "That nighttime luminance levels provided by pavement markings that may be adequate for younger drivers may be less than adequate for older drivers."[10] Therefore, rather than examining the amount of time until retroreflectivity levels fall below a minimum recommended level, the following assessment accounts for the retroreflectivity readings over time above minimum recommended levels as a net benefit. The net benefits are calculated by a summation of the area between the averaged retroreflective readings and the FHWA recommended minimum until reading fall below the minimum value.

Based upon the service lives of the white traffic markings derived from recorded retroreflectivity values, the net benefits of the materials and the benefit per total cost per foot are summarized in Table 8.

Table 8. Benefit analysis summary of white markings for both types.

Material	Benefit (mcd/lx/m2*days)	Benefit per Cost/Foot
LPM 1400 White Skip	43,254	34,603
LPM 1200 White Skip	55,575	44,460

Overall for the white skip lines, the experimental marking showed only 78% the benefit of the control. Since both marking types have the same cost, the benefit per cost per foot values result in the same percentage breakdown. In addition, since the analyses per color vary, with each marking appearing to be similarly superior for one color (yellow), this benefit analysis for each material can be considered equal; both materials have virtually identical benefit.

It is important to note that the measured benefit for a marking in Vermont is directly related to how early in the marking season a line is placed. If it is placed at the beginning of the season the public has the entire season to benefit from superior performance, while if a marking is placed towards the end of the season it normally is quickly degraded with the onset of the plowing season, making the marking far less beneficial with respect to safety and life cycle cost. Therefore, the benefit analysis can only be used as a qualitative comparison between two materials that have been placed on near identical dates.

---

[10] Graham, Johnny R., Harrold, Joseph K., King, L. Ellis, "Pavement Marking Retroreflectivity Requirements for Older Drivers", Transportation Research Record, Volume 1529, pp. 65-70, 1996.

6. Summary and Recommendations

In an effort to enhance visibility during evening rain events, the Agency evaluated a traffic marking polyurea with "wet night" properties produced by 3M^{TM} known as "3M^{TM} All Weather Liquid Pavement Marking 1400 (LPM 1400)", which was recessed to a proper depth. Markings were applied and assessed for both yellow edge line and white skip line applications. Long term performance was assessed in terms of retroreflectivity and wear. These characteristics were compared to a common application of a similar recessed polyurea. Service life estimates based upon retroreflectivity levels were derived from FHWA recommended minimum values.

The experimental and control polyurea traffic markings were applied to a portion of the Richmond – South Burlington project, IM 089-2(39), located along I-89 northbound by personnel from L&D Safety Markings. All of the experimental and control markings were found to be above the minimum required retroreflectivity for new markings during the initial site visit, with the LPM 1400 exhibiting 26% higher readings for yellow edge lines, but the control exhibiting 13% higher readings for white skip lines. The experimental and control polyurea traffic markings fell below the FHWA minimum recommended value of 150 mcd/m^2/lx for white markings on approximately day 184 and 201 following application, respectively and the value of 100 mcd/m^2/lx for yellow markings never being reached other than during one site visit during an inopportune wintertime visit. It is important to note that these values were estimated from a scatter plot of retroreflectivity values over time. This life cycle is likely largely influenced by winter maintenance practices and high traffic volume. The evaluation term ended during the summer of 2010 with the restriping of the lines. Unfortunately, the wet reflective properties of the permanent tape makings could not be assessed during this study as a special retroreflectometer is required to test wet reflectivity, which was not available for this evaluation.

A cost analysis shows that the cost of the experimental LPM 1400 is identical to that of the LPM 1200 control, as the binder is the same price, the glass bead and element applications were the same, and application and recessing methods and thicknesses were identical. A benefit analysis, which gives credit to a marking being well above FHWA minimum retroreflectivity values, concluded that both markings display approximately the same benefit, with the LPM 1400 more beneficial for the yellow markings and the LPM 1200 more beneficial for the white.

It was hoped that the LPM 1400 products would be less vulnerable to winter maintenance practices, resulting in higher maintained retroreflectivity values and greater durability over time. The yellow edgeline markings, for both products, upheld satisfactorily, remaining above the recommended minimums following two winter seasons. Unfortunately, with respect to retroreflectivity, this just was not the case for the white skip markings, most likely due to the centerline location, where markings are subject to more traffic changing lanes and a greater number of plowing events (typically the centerline is hit twice, when each lane is plowed). The durability levels of the markings could be considered satisfactory, as many of the markings remain mostly intact and visible under lit conditions. Based on these findings, 3M™ All Weather Liquid Pavement Marking 1400 would be recommended for future interstate recessed markings.

REFERENCES

1. "3M™ All Weather Elements Product Bulletin", "3M™ Traffic Safety Systems Division, January 2010.

2. Kipp, Wendy, *Work Plan for Research Investigation: 3M™ Stamark High Performance Wet Reflective Tape Series 380WR ES and 3M™ Stamark All Weather Liquid pavement marking (LPM) Series 1400, Work Plan No. WP-2008-3*. Vermont Agency of Transportation, 2008.

3. "3M™ All Weather Liquid Pavement Marking Series 1400", 3M™ Traffic Safety Systems Division, October 2009.

4. AASHTO M 247-81 "Standard Specification for Glass Beads Used in Traffic Paints" Type I gradation 1.5 index glass beads, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 27th Edition 2007.

5. ASTM D1155 "Standard Test Method for Roundness of Glass Spheres", ASTM International, West Conshohocken, PA, <www.astm.org>.

6. ASTM D1213 "Test Method for Crushing Resistance of Glass Spheres", ASTM International, West Conshohocken, PA, <www.astm.org>.

7. ASTM E 1710-97, "Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer," ASTM International, West Conshohocken, PA, <www.astm.org>.

8. ASTM D 913-03, "Evaluating Degree of Resistance to Wear of Traffic Paint," ASTM International, West Conshohocken, PA, <www.astm.org>.

9. ASTM D 6359-99, "Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments," ASTM International, West Conshohocken, PA, <www.astm.org>.

10. Graham, Johnny R., Harrold, Joseph K., King, L. Ellis, "Pavement Marking Retroreflectivity Requirements for Older Drivers", Transportation Research Record, Volume 1529, pp. 65-70, 1996.

APPENDIX A

Table A1. All retroreflectivity measurements and appearance ratings for LPM 1400 yellow edgelines.

		10/17/2008	5/4/2009	7/28/2009	9/16/2009	12/2/2009	2/2/2010	4/13/2010
Test Site	Reading #	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental
		NB Yellow	NB Yellow	NB Yellow	NB Yellow	NB Yellow	NB Yellow	NB Yellow
Test Site 1 (MM 81.5)	1	545	431	310	347	173	17	280
	2	607	373	358	368	206	20	294
	3	545	372	384	390	190	22	232
	4	611	330	379	370	177	22	280
	5	605	336	379	397	186	3	296
Average		**582.60**	**368.40**	**362.00**	**374.40**	**186.40**	**16.80**	**276.40**
Durability		**100**	**95**	**95**	**95**	**90**	**90**	**85**
Std. Dev.		**34.39**	**40.24**	**30.75**	**19.78**	**12.90**	**7.98**	**25.94**
Test Site 2 (MM 81.7)	1	502	342	293	336	146	28	267
	2	456	350	277	345	126	31	278
	3	548	392	342	379	147	17	289
	4	561	339	311	364	129	7	290
	5	500	304	326	306	146	9	251
Average		**513.40**	**345.40**	**309.80**	**346.00**	**138.80**	**18.40**	**275.00**
Durability		**100**	**95**	**95**	**95**	**90**	**90**	**85**
Std. Dev.		**42.03**	**31.46**	**25.78**	**27.90**	**10.38**	**10.85**	**16.36**
Test Site 3 (MM 81.9)	1	475	259	275	294	150	20	222
	2	431	278	264	270	141	20	218
	3	407	303	284	287	148	20	215
	4	481	291	295	269	143	15	215
	5	472	301	260	270	153	9	223
Average		**453.20**	**286.40**	**275.60**	**278.00**	**147.00**	**16.80**	**218.60**
Durability		**100**	**100**	**95**	**95**	**90**	**90**	**85**
Std. Dev.		**32.51**	**18.24**	**14.36**	**11.68**	**4.95**	**4.87**	**3.78**

Numbers in red indicate readings that were below the FHWA recommended minimum of 150 mcd/lx/m^2 for a freeway.

Table A1. Continued

		10/17/2008	5/4/2009	7/28/2009	9/16/2009	12/2/2009	2/2/2010	4/13/2010
Test Site 4 (MM 82.1)	1	283	292	235	269	124	Snow	211
	2	384	275	313	353	159		230
	3	400	296	289	290	132		220
	4	348	305	307	322	138		244
	5	378	269	275	304	138		216
Average		**358.60**	**287.40**	**283.80**	**307.60**	**138.20**	**Snow**	**224.20**
Durability		**10**	**95**	**95**	**95**	**90**		**85**
Std. Dev.		**46.27**	**14.98**	**31.13**	**31.94**	**12.97**		**13.08**
Test Site 5 (MM 82.3)	1	452	287	286	297	151	Snow	233
	2	407	270	243	252	132		190
	3	378	246	266	336	129		192
	4	409	249	244	248	143		212
	5	428	259	289	284	150		220
Average		**414.80**	**262.20**	**265.60**	**283.40**	**141.00**	**Snow**	**209.40**
Durability		**100**	**95**	**95**	**95**	**90**		**85**
Std. Dev.		**27.42**	**16.75**	**22.03**	**36.02**	**10.12**		**18.41**
Overall Average		**464.52**	**309.96**	**299.36**	**317.88**	**150.28**	**17.33**	**240.72**
Overall SD		**86.21**	**47.38**	**42.32**	**45.11**	**21.09**	**7.70**	**33.43**

Numbers in red indicate readings that were below the FHWA recommended minimum of 150 mcd/lx/m^2 for a freeway.

Table A2. All retroreflectivity measurements and appearance ratings for LPM 1200 yellow edgelines.

Test Site	Reading #	10/17/2008 LPM 1200 - Control NB Yellow	5/4/2009 LPM 1200 - Control NB Yellow	7/28/2009 LPM 1200 - Control NB Yellow	9/16/2009 LPM 1200 - Control NB Yellow	12/2/2009 LPM 1200 - Control NB Yellow	2/2/2010 LPM 1200 - Control NB Yellow	4/13/2010 LPM 1200 - Control NB Yellow
Test Site 6 (MM 83.2)	1	377	284	264	288	145	34	233
	2	374	272	248	294	147	8	244
	3	344	328	257	306	150	6	219
	4	331	290	228	250	147	19	201
	5	355	294	224	278	147	15	213
Average		**356.20**	**293.60**	**244.20**	**283.20**	**147.20**	**16.40**	**222.00**
Durability		**100**	**95**	**95**	**95**	**90**	**90**	**80**
Std. Dev.		**19.59**	**20.95**	**17.61**	**21.15**	**1.79**	**11.15**	**16.85**
Test Site 7 (MM 83.5)	1	369	293	301	305	147	9	260
	2	402	306	338	314	156	6	271
	3	375	314	326	323	151	8	262
	4	367	342	352	333	154	4	281
	5	396	313	319	302	137	3	245
Average		**381.80**	**313.60**	**327.20**	**315.40**	**149.00**	**6.00**	**263.80**
Durability		**100**	**95**	**95**	**95**	**85**	**85**	**85**
Std. Dev.		**16.12**	**17.95**	**19.28**	**12.82**	**7.52**	**2.55**	**13.41**
Overall Average		**369.00**	**303.60**	**285.70**	**299.30**	**148.10**	**11.20**	**242.90**
Overall SD		**21.63**	**21.20**	**47.08**	**23.66**	**5.24**	**9.39**	**26.30**

Numbers in red indicate readings that were below the FHWA recommended minimum of 150 mcd/lx/m^2 for a freeway.

Table A3. All retroreflectivity measurements and appearance ratings for LPM 1400 white skip lines.

		10/17/2008	5/4/2009	7/28/2009	9/16/2009	12/2/2009	2/2/2010	4/13/2010
Location: Starts at MM 81.5 and the Readings were taken at every fifth skip.	Reading #	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental	LPM 1400 - Experimental
		NB White -	NB White -	NB White -	NB White -	NB White -	NB White -	NB White -
	1	439	70	71	60	26	30	31
	2	672	81	103	89	47	35	66
	3	701	100	107	94	47	36	63
	4	632	97	90	91	42	37	65
	5	488	100	66	89	46	31	30
	6	652	100	91	70	43	35	47
	7	593	73	98	89	39	31	59
	8	687	84	88	97	32	36	73
	9	781	80	85	98	45	34	82
	10	770	83	138	115	52	35	79
	11	623	95	98	94	46	28	75
	12	438	113	96	119	59	26	58
	13	669	112	127	89	66	30	68
	14	728	70	116	96	56	28	81
	15	660	111	98	129	58	25	68
	16	636	110	112	108	61	20	72
Overall Average		635.56	92.44	99.00	95.44	47.81	31.06	63.56
Durability		100	95	95	90	85	85	85
Std. Dev.		103.10	15.25	18.60	16.98	10.63	4.80	15.78

Numbers in red indicate readings that were below the FHWA recommended minimum of 150 mcd/lx/m^2 for a freeway.

Table A4. All retroreflectivity measurements and appearance ratings for LPM 1200 white skip lines.

		10/17/2008	5/4/2009	7/28/2009	9/16/2009	12/2/2009	2/2/2010	4/13/2010
Location: Starts at MM 83.5 and the Readings were taken at every fifth skip.	Reading #	LPM 1200 - Control	LPM 1200 - Control	LPM 1200 - Control	LPM 1200 - Control	LPM 1200 - Control	LPM 1200 - Control	LPM 1200 - Control
		NB White -	NB White -	NB White -	NB White -	NB White -	NB White -	NB White -
	1	649	111	134	138	86	19	93
	2	775	127	121	132	72	20	92
	3	814	159	135	140	60	21	88
	4	768	168	148	145	67	18	95
	5	630	139	134	119	77	18	101
	6	681	117	114	158	49	12	79
Overall Average		719.50	136.83	131.00	138.67	68.50	18.00	91.33
Durability		100	95	95	95	90	90	85
Std. Dev.		75.93	22.91	11.93	13.02	13.00	3.16	7.39

Numbers in red indicate readings that were below the FHWA recommended minimum of 150 mcd/lx/m^2 for a freeway.