3M Stamark Polyurea,
Liquid Pavement Markings Series 1200 and 1000
Lyndon-Barton Vermont
Final Report

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Reporting on Work Plan 2001-R-3

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16. Abstract
This report documents the evaluation of two versions of a propriety liquid polyurea pavement marking material. A reported highly reflective element comprised of microcrystalline ceramic beads was also evaluated. The project was located on Vermont Interstate 91 between the towns of Lyndon and Barton. This was an 18.01-mile section of highway, and consisted of two experimental pavement markings, a standard waterborne paint, and a control thermoplastic marking.

Retroreflectivity and durability were documented over a period of four years. A minimum acceptable retroreflectivity threshold of 100 mcdl was selected in accordance with FWHA recommendations. The cost of each marking per linear foot was then divided by the number of months the applicable marking was in service to determine the cost per linear foot per month of each marking. The thermoplastic markings were found to have the longest service life, and the waterborne paints were found to be the most cost effective. Surface application of the experimental liquid pavement marking is not recommended at this time.

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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 markings materials during 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 the 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 is a loss of both daytime and nighttime visibility.

In an effort to increase the service lives of pavement markings while maintaining acceptable visibility, the Vermont Agency of Transportation applied an two variations of an experimental marking material to a newly construction paving project in the northbound lane of Interstate 91 between the towns of Lyndon and Barton in the fall of 2001. The objective of this research initiative was to evaluate the performance of two versions of a propriety liquid polyurea pavement marking material. In addition to assessing the pavement marking material, or binder, for resistance to abrasion, a reported highly reflective element comprised microcrystalline ceramic beads was also evaluated.

The following final report assesses the overall performance of the experimental pavement markings in terms of wear and retroreflectivity, otherwise known as luminance. For comparative purposes, both standard thermoplastic and waterborne paint were applied in conjunction with this research initiative. This report also contains information related to the experimental product and summarizes all surveillance and testing methods, data collection results and associated findings

PRODUCT DETAILS

The two experimental markings incorporated into the investigation are known Stamark Liquid Pavement Marking (LPM) Series 1000 and 1200 manufactured by the Traffic Control Division of 3M Company, Inc. of St. Paul, MN. 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 experimental marking materials display 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, the existing pavement marking 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, LPM 1000 and 1200 can be applied to new asphalt pavement as soon as the material has cooled and can support weight and movement of the application equipment.

Two gradations of glass beads were supplied for drop-on application in association with the experimental markings. The first series of reflective elements applied to both the LPM 1000 and 1200 markings were comprised of glass beads in compliance with the Type I standard maximum gradation of 850 µm of the American Association of State Highway and Transportation Officials' (AASHTO) specification M247, "Glass Beads Used in Traffic Paint." The second type of reflective elements applied only to the LPM 1200 markings is composed of proprietary microcrystalline ceramic bead. A sketch of the ceramic beads is shown in Figure 1 below. It is important to note the larger size of the ceramic bead in comparison to the standard glass beads. Previous studies have shown that larger beads typically required at an increased application thickness to ensure adequate adhesion. Figure 2 displays an actual photograph of the microcrystalline elements and standard glass beads.

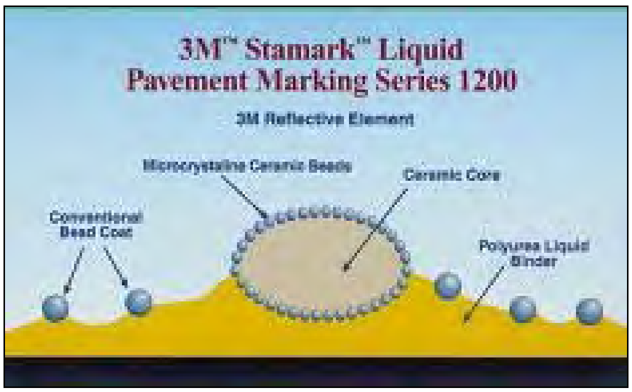

Figure 1 – Depiction of Ceramic Bead

Figure 2 – Bead Comparison

PROJECT DETAILS

In association with the federally approved workplan, WP 2001-R-3, ""3M Stamark Polyurea, Liquid Pavement Marking Series 1200 & Series 1000", all pavement marking were applied to the Lyndon/Barton highway rehabilitation project, IM 091-3(10) in the fall of 2001. This project included cold planing and resurfacing of the northbound lane and northbound interchange ramps with a leveling course and Type III Superpave wearing course, pavement markings, guardrails, signs and other incidental items. A Type III wearing course contains a nominal aggregate size of ½" resulting in a rougher a 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 2002 average annual daily traffic (AADT) along I-91 NB was 5100. This is a lower AADT for Vermont which means that the markings in this area would not be subject to as much abrasion from vehicle tires as compared to markings in high AADT locations.

As shown in Table 1, two types of durable marking binders were applied to the highway in association with the construction project as well as standard waterborne markings. The control marking material consisted of Ennis SG 70 thermoplastic. The Ennis SG 70, 3M LPM 1000, and standard waterborne marking materials were applied with standard AASHTO M247 Type I beads supplied by the marking manufacturer.

Lyndon - Barton Marking Material Locations			
Section Type	**Bead Type**	**Mile Marker**	**Total Length**
3M LPM 1200	AASHTO-1 & 3M Ceramic Bead	137.49 - 141.65	4.16
3M LPM 1000	AASHTO-1	141.65 - 146.00	4.35
Lafarge Waterborne Paint	AASHTO-1	146.00 - 150.75	4.75
Ennis SG 70 Thermoplastic	AASHTO-1	150.75 - 155.50	4.75

Table 1 – Pavement Marking Summary

INSTALLATION

Placement of the LPM Series 1000 and 1200 began on Thursday, October 18th, 2001. Striping operations performed by L & D Safety Markings from Berlin, Vermont, commenced at 11:00 AM. The timing allowed for the pavement surface to be dry as well as ambient air and surface temperatures to rise within the manufactures specifications. Installation of the LPM markings was completed over the course of two days and included all 6" edge and skip lines. It should be noted that the roadway and weather conditions greatly affect the rate of cure and resulting performance. Table 2 provides an installation summary and daily temperature range for each marking.

Lyndon - Barton Installation Data			
Date - Time	Temperature	Weather	Notes
10/01/01, 11:00 am	55^o F - 65^{o}F	Clear	Thermoplastic
10/18/01, 12:00 pm	30^o F - 45^o F	Partly Cloudy	LPM 1200 & 1000
10/19/01, 12:30 pm	45^o F - 60^o F	Cloudy	LPM 1200 & 1000
11/02/01, 9:00 am	45^o F - 60^o F	Partly Cloudy	Waterborne Paint

Table 2 – Pavement Marking Application

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." In examining Table 2 above, it is clear that this specification was not met during the first day of the LPM application. However, this specification had yet been not established during the time of application and the manufacturer does recommend a minimum application temperature of 40^{o}F and rising. In either case, the ambient and pavement conditions were most likely not ideal for optimum performance on either day. Please note that all yellow markings were applied on the 18th and all white markings were applied on the 19th. As one other final consideration, the preferred application thickness as reported by the manufacturers is 18 to 20 mils while the specified application thickness of thermoplastic is 90 mils. While polyurea is known to display an excellent hardness, the application thickness of thermoplastic may allow for additional substrate loss before visible wear. Additional installation details are provided in an initial report, U 2003-5.

SURVEILLANCE AND TESTING

In accordance with the work plan, test sites were established throughout the length of the project 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 2005 utilizing a 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. 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 specifications 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.

The first site visit was conducted on, October 19th, one to two days following application of the LPM pavement markings. All pavement markings were found to be intact. A summary of initial retroreflectivity readings are provided below in Table 3. Please note that all LPM1000 and LPM 1200 markings 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 marking and 175 mcdl for yellow markings within 14 days of application. However, compliance with the ASTM standard could not be assessed with reference to the thermoplastic or waterborne markings as the initial data was collected in excess of 14 days.

Lyndon - Barton: Initial Retroreflectivity Readings Experimental Materials (mcdl/m2/lux)					
Material	**Test Site**	**Mile Marker**	**White Edge Line**	**White Skip Line**	**Yellow Edge Line**
3M LPM 1200	1	138.10	1209	1302	1291
	2	139.40	1279	1444	1213
	3	140.80	1148	1479	1154
	4	141.45	1087	1349	1091
		Average:	**1181**	**1393**	**1187**
		Standard Deviation:	**82**	**82**	**85**
3M LPM 1000	1	142.50	318	346	249
	2	143.50	338	349	230
	3	144.45	282	342	248
	4	145.10	305	358	225
		Average:	**311**	**349**	**238**
		Standard Deviation:	**24**	**7**	**12**

Table 3 – Initial Retroreflectivity Readings

In examining the data sets, initial results from the LPM Series 1200 and 1000 are promising and were found to be well above minimum standards. Specifically, the retroreflectivity of the LPM 1200 markings were found to be 5 to 7 times an order of magnitude greater than the minimum specification and was most likely contributed to the ceramic beads dropped onto the marking binder. The readings for the LPM 1000 markings were found to be comparable to that of thermoplastic. The standard deviations for the LPM 1200 markings are somewhat greater as compared to the LPM 1000 marking. However, it is important to consider the magnitude of the values for both the average and standard deviation. In this case, both markings displayed a similar standard deviation. In addition, these are low standard deviations when compared to other marking materials indicating constancy of the marking material as well as drop on rate of the reflective elements.

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 4.

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 4- FHWA Recommendations

WHITE EDGE LINES

As recommended by the FHWA, a minimum recommended retroreflectivity of 150 mcdl is normally the selected benchmark however, because of the extreme climate at this location and later seasonal installation date, 100 mcdl was selected as the benchmark for evaluating white interstate markings. Table 5 contains a summary of average reflectance for each composition of white edge lines. Please note that any readings below 100 mcdl are highlighted in red.

Lyndon - Barton: White Edge Retroreflectivity Averages ($mcdl/m^2/lux$)				
Date of Collection	**LPM 1200**	**LPM 1000**	**Thermoplastic**	**Waterborne Paint**
10/19/2001	1181	311	313	N/A
11/19/2001	755	315	252	N/A
12/3/2001	N/A	N/A	N/A	255
2/26/2002	124	87	68	36
3/14/2002	82	71	48	27
4/2/2002	120	92	N/A	17
4/5/2002	N/A	N/A	86	N/A
4/11/2002	123	95	77	30
4/17/2002	132	100	84	N/A
4/26/2002	148	110	70	28
5/10/2002	143	102	79	29
6/13/2002	141	101	103	-----
7/16/2002	157	106	122	-----
9/26/2002	156	109	135	-----
2/20/2003	43	40	63	-----
5/15/2003	90	79	95	-----
6/26/2003	97	73	91	-----
11/17/2003	83	88	59	-----
12/5/2003	276*	170*	141*	-----
3/26/2004	32	42	30	-----
4/29/2004	79	69	61	-----
5/27/2004	86	72	59	-----
8/3/2004	89	67	-----	-----
10/13/2004	83	60	-----	-----
3/30/2005	34	42	-----	-----
6/29/2005	61	53	-----	-----

Notes:

----- indicates that pavement markings have been restriped

XXX* indicates salt on the lines

N/A indicates that no readings were collected

Table 5 – Retroreflectivity Summary for White Edge Line

As anticipated, a significant drop in retroreflectivity, 458 mcdl on average, is evident across all markings following the first winter season. This is most likely attributed to shearing effects resulting from winter maintenance practices. Specifically, while the LPM 1200 Series with ceramic beads provides the greatest initial retroreflectivity, it also displays the highest response to plowing during the first winter season with an average loss of 1100 mcdl. Wear readings collected during this timeframe were found to be between 7 and 8. Throughout the investigation, the thermoplastic markings appear to be comparable to the LPM 1000 markings in terms of luminance. The LPM 1200 markings were only found to display a slightly higher retroreflectivity of 43 mcdl on average in comparison to both the LPM 1000 and thermoplastic markings during the spring and summer of 2002. During subsequent data collection events, all markings displayed a similar retroreflectivity.

YELLOW EDGE LINES

A similar analysis was performed on the yellow pavement markings with a minimum acceptable retroreflectivity of 65 mcdl as displayed in Table 6.

Lyndon - Barton: Yellow Line Retroreflectivity Averages (mcdl/m²/lux)				
Date of Collection	**LPM 1200**	**LPM 1000**	**Thermoplastic**	**Waterborne Paint**
10/19/01	1187	238	91	N/A
11/19/01	899	198	73	N/A
12/03/01	N/A	N/A	N/A	233
02/26/02	121	60	38	46
03/14/02	149	61	45	57
04/02/02	239	67	N/A	41
04/05/02	N/A	N/A	58	N/A
04/11/02	218	70	56	64
04/17/02	218	70	59	N/A
04/26/02	243	83	44	48
05/10/02	230	77	63	54
06/13/02	249	80	73	-----
07/16/02	238	83	81	-----
09/26/02	252	87	91	-----
02/20/03	105	38	37	-----
05/15/03	173	58	46	-----
06/26/03	174	59	62	-----
11/17/03	109	46	46	-----
12/05/03	320*	213*	134*	-----
03/03/04	95	179*	43	-----
04/29/04	143	68	56	-----
05/27/04	173	75	59	-----
08/03/04	150	76	-----	-----
10/13/04	158	81	-----	-----
03/23/05	52	30	-----	-----
06/07/05	82	51	-----	-----

Notes:

----- indicates that pavement markings have been restriped

XXX* indicates salt on the lines

N/A indicates that no readings were collected

Table 6 – Retroreflectivity Summary for the Yellow Edge Lines

A significant drop in retroreflectivity, 339 mcdl on average, is evident for all yellow markings following the first winter season. Once again, the LPM Series 1200 displayed the highest initial retroreflectivity along with the highest response to plowing during the first winter season with an average loss of 948 mcdl. However, the LPM 1200 markings displayed a noticeably higher retroreflectivity during 2002 and 2003 with average readings of 235 and 151, respectively in comparison to the LMP 1000 and thermoplastic markings. These markings were found to have average retroreflectivity readings of 79 and 67 mcdl, respectively during 2002 and 52 and 48 mcdl, respectively, during 2003.

SERVICE LIFE

Service life estimates for each white line pavement marking could not be determined from Table 5 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 100 mcdl, as shown in Figure 3. Please note that only white lines were modeled for this analysis due to the inherent variability of yellow pavement markings. In addition, due to the seasonal rebound easily identifiable in Figure 3 following damage from winter maintenance practices, the estimated number of days prior to falling below the benchmark of 100 mcdl was based on the last time the marking achieved the minimum recommendation.

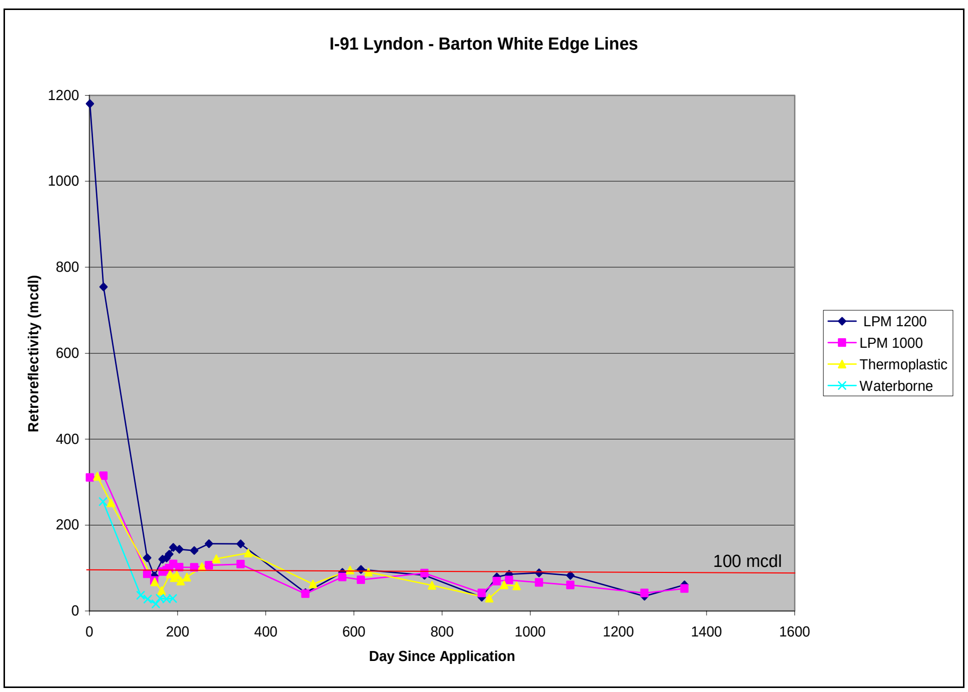

Figure 3 – Retroreflectivity Graph of White Edge Lines

Estimates service lives for the white pavement markings are as follows in ascending order:

Waterborne Paint – 90 days
3M LPM 1000 – 360 days
3M LPM 1200 – 410 days
Ennis SG 70 Thermoplastic – 440 days

The estimates are substantially affected by winter operations, particularly the waterborne paint service life.

COST ANALYSIS

All costs for the application of the various pavement markings were paid as part of the Lyndon – Barton construction project. The application cost for the 3M LPM Series 1000 and 1200 were approximately $0.68/LF and $0.85/LF respectively. The cost fo the application of the thermoplastic was $0.37/LF. The cost for the application of the waterborne markings was approximately $0.04/LF. The cost per month for each marking was calculated by dividing the total cost of the application per linear foot by the estimate service lives in months. The cost analysis is shown in Table 7.

Lyndon – Barton Cost Analysis for White Edge Lines				
	Elapsed Time			
Marking Type	Days	Months	Cost	Cost/Month
Ennis SG 70 Thermoplastic	440	14.5	$0.37/LF	$0.03
3M LPM 1000	360	12	$0.68/LF	$0.06
3MLPM 1200	410	13.5	$0.85/LF	$0.06
Waterborne Paint	90	3	0.04/LF	$0.01

Table 7 - Cost Analysis (White Edge Lines)

The standard waterborne paint was found to have the lowest material cost per month along with the shortest service life. Conversely, the 3M LPM pavement markings were found to be the most expensive and the second longest service life. Ennis SG 70 thermoplastic was found to have the longest service life. Overall this material appears to be the most cost effective in consideration to the cost per month and duration of service life.

SUMMARY

Data collection on these different markings were gathered using uniform methods, collected on the same days and weather conditions and without favoring one type of material over another. After only 1.20 years of service all of the white edge lines on this project have fallen below the FHWA Recommendations. Surprisingly, the yellow markings appeared to exhibit a much longer service life with consideration to retroreflectivity at approximately four years for both the LPM Series 1000 and 1200 yellow edge line closely followed by thermoplastic. This is somewhat counterintuitive due to the colder application temperature of the yellow pavement markings as compared to the white pavement markings. However, because this is evident for all durable markings applied with different application equipment as well as on different days, it is difficult to ascertain the causation of the phenomenon.

The data evidenced a large drop in readings on all materials following the first winter season. As concurrent studies have show, larger diameter glass beads generally require a larger binder film thickness to provide compatible and adequate bond to surrounding substrate. Additionally, lower ambient air temperatures may have increased the time needed for proper cure potentially resulting in insufficient bonding. In association with shearing effects produced by winter maintenance practices, the larger diameter beads may have become dislodges resulting in a great loss of retroreflectivity. However, this assessment does not consider any associated benefits from retroreflectivity results above the minimum recommendation although investigations have shown the importance of bridge markings for older drivers and inclement weather condition. Overall, the SG 70 thermoplastic markings was shown to retain its retroreflectivity capability longer than all other marking materials incorporated into the investigation. While standard waterborne paint proved to be the most cost effective, it would require extensive restriping.

Data collection on these pavement markings has been completed. Application of surface applied LPM Series 1200 and 1000 is not recommended at this time. However, that is subject to change if the larger ceramic beads can be protected from winter maintenance practices and other similar abrasion.

References:

American Society for Testing and Materials (ASTM) D 711, “Test Method for No-Pick-Up Time of Traffic Paint” American Society for Testing and Materials

American Association of State Highway and Transportation Officials’ (AASHTO) specification M 247 “Glass Beads Used in Traffic Paint

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”

American Society for Testing and Materials (ASTM) D 6359-99, “Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments”

American Society for Testing and Materials (ASTM) D 913-03, “Evaluating Degree of Resistance to Wear of Traffic Paint”

Appendix A

Protocol for the Cleaning of Line Stripping 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.