Evaluation and Comparison of
Epoplex LS-50 Epoxy
Lyndon/Sheffield IM 091 – 3(11)
Final Report

July, 2007

Report 2007 - 11
Reporting on Work Plan 2002-R-8

State of Vermont
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Materials and Research Section

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16. Abstract
In an effort to increase the service lives of durable pavement markings while maintaining acceptable visibility, the Vermont Agency of Transportation applied an experimental durable pavement marking, known at Epoplex LS50, to a newly constructed paving project located in the southbound lane of Interstate 91 between the towns of Lyndon and Sheffield in the fall of 2002.

Following the placement of the markings, data collection, including retroreflectivity and wear readings, was conducted using uniform methods over a three year period. Most of the epoxy markings were not found to be in compliance with ASTM 6359, “Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments.” Additionally, a significant drop in retroreflectivity, 156 mcdl on average for the white markings and 95 mcdl on average for the yellow markings, was evident following the first winter season. Interestingly, although retroreflectivity readings continued to decline overtime, as would be expected, the wear readings were quite impressive at roughly 8 three and half years following application.

A cost analysis was performed with consideration to FHWA’s minimum recommended retroreflectivity. A decay model of a standard marking, thermoplastic was also incorporated for comparative purposes. Both the epoxy and thermoplastic markings were found to have comparable costs in terms of applicable service life as defined by a minimum threshold for retroreflectivity.

Overall, the application of epoxy is not recommended for high speed locations at this time. The durability of the binder material may make it attractive for lower speed locations or locations with overhead lighting to assist night time visibility.

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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 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.

In an effort to increase the service lives of durable pavement markings while maintaining acceptable visibility, the Vermont Agency of Transportation applied an experimental durable pavement marking to a newly constructed paving project located in the southbound lane of Interstate 91 between the towns of Lyndon and Sheffield in the fall of 2002. This examination focused on a new type of epoxy pavement marking, known as LS50. Please note that in accordance with the work plan, 2002-R-8, glass beads, roughly 3 to 4 times larger than standard glass beads, known as Visibeads Plus were supposed to be dropped onto the epoxy binder in a half mile segment during application to assess the beads for retroreflectivity, bead retention and wet night visibility. However, there are no records of the experimental bead application. Therefore, Visibeads will not be addressed in this report.

The following final report assesses the overall performance of the epoxy pavement markings in terms of durability 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:

According to the manufacturer, Epoplex of Maple Shade, NJ, "LS50 is the most popular fast setting epoxy formulation for durable epoxy pavement marking application in the world. This formulation has a drying time of less than 10 minutes at 77^{o}F when tested under ASTM D-711. Epoplex LS50 exhibits excellent durability on concrete and asphalt surfaces and has excellent initial and retrained retroreflectivity." Epoxy markings are a two part system formulated and designed to provide a simple volumetric ratio of the two components. In addition, the manufacturer claims that these markings provide for excellent bond strength assuring good adhesion to a variety of substrates along with high ultraviolet light stability. In addition, this formulation reportedly rapid sets at a wide range of temperatures. It is also important to note that specialized equipment is required for application. With regards to preparation, the pavement surface must be clean and dry prior to application. In addition, LS50 epoxy must be applied only when atmospheric and surface temperatures are 40^{o}F or higher. For additional information regarding the product, please refer to Attachment A.

PROJECT DETAILS:

In association with a federally approved work plan, 2002-R-8, all pavement markings were applied to the Lyndon/Sheffield highway rehabilitation project, IM 091-3(11), in the fall of 2002 along the southbound lanes of I 91 between mile marker (MM) 137.19 (Exit 24) and MM150.70, for a total length of 13.51 miles. The project included cold planning and resurfacing of the southbound travel lanes with a Type III wearing course, shoulders, rest area and interchanges, Exit 23 and 24 off ramp, new pavement marking, limited guard rail improvements, and other incidental items. It is important to note that a type III with a nominal aggregate size of ½" resulting in a rougher pavement surface as compared to a Type IV 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 average annual daily traffic (AADT) in 2002 was 5100 between Exits 24 and 25. This is a moderate to low AADT for Vermont which indicates that the markings in this area may not be subjected to higher amounts of abrasion from vehicle tires. This region is subjected to an average snowfall rate of 100" per year, a moderate snowfall rate for Vermont.

INSTALLATION:

Pavement application was completed by Luck Brothers on Friday, October 18th, 2002. Placement of the Epoplex LS50 began on Tuesday, October 22, 2002. Striping operations performed by Straight Line, commenced at 10:00 AM. The timing allowed for the pavement surface to be dry as well as ambient air and surface temperatures within the manufactures specifications. Installation of the LS50 was completed over the course of two days and included all 6" edge and skip lines. It should be noted that roadway and weather conditions greatly affect the rate of cure and resulting performance. Table 1 provides an installation summary and daily temperature range for each marking.

Lyndon-Sheffield Installation Data					
Date	Segment	Temperature	Weather	Dew Point	Notes
10/22/2002	1	19^{o}F - 43^{o}F	Sunny	23^{o}F	Centerline and Yellow Edge Line
10/23/2002	2	23^{o}F - 43^{o}F	Sunny	23^{o}F	White Edge Line

Table 1 – Pavement Marking Summary

In examining the weather data, it is important to consider both the temperature and dew point. As stated previously, the manufacturer recommends a minimum ambient and roadway temperature of 40^{o}F along with a dry surface. As shown within Table 1, ambient air temperatures feel below manufacturer's specifications with average temperatures for October 22nd and October 23rd of 31^{o}F and 32^{o}F, respectively as reported by

Weatherunderground.com. In addition, the dew point was for these two days was 23^{o}F. Dew points indicate the amount of moisture in the air. When the dew point temperature and the air temperature are the equal, the air is saturated. Given the air temperatures in association with the dew point, it is likely that the ambient moisture content was high indicating an elevated potential for condensation on the surface of the pavement. This coupled with lower ambient air temperatures may have increased the amount of time needed for curing. Extended cure times may result in inadequate bond strengths to both the underlying pavement as well as the glass beads.

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. Two test sites are shown in Figures 1 and 2 below.

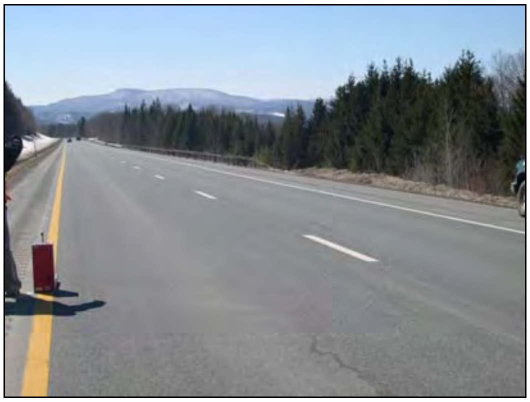

Figure 1 -Test Site 1, MM 150.00

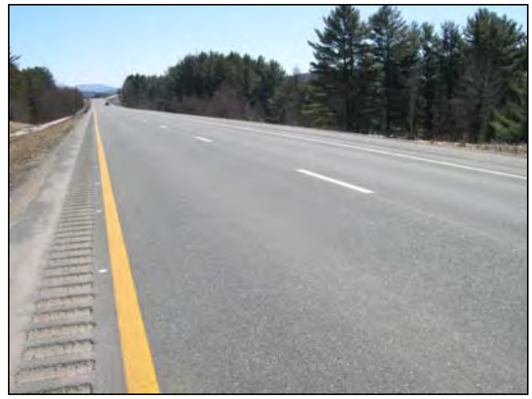

Figure 2 -Test Site 3, MM 143.70

The first site visit was conducted on November 5th, thirteen to fourteen days following application of the LS50 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 most of the epoxy markings were not 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. Any readings below the referenced ASTM standard are highlighted in red.

Lyndon - Sheffield: Initial Retroreflectivity Readings (mcdl/m2/lux)			
Test Site 1 - MM 150.00	White EL	White Skip	Yellow CL
1	216	111	125
2	222	130	121
3	231	128	143
4	209	-----	147
5	203	-----	113
Average	**216**	**123**	**130**
Standard Dev.	11	10	15
Test Site 2 - MM 146.30	White EL	White Skip	Yellow CL
1	197	226	154
2	250	204	127
3	313	194	144
4	249	-----	125
5	336	-----	173
Average	**269**	**208**	**145**
Standard Dev.	56	16	20
Test Site 3 - 143.70	White EL	White Skip	Yellow CL
1	259	197	185
2	340	195	164
3	341	243	133
4	336	-----	140
5	341	-----	148
Average	**323**	**212**	**154**
Standard Dev.	36	27	21
Test Site 4 - MM 140.85	White EL	White Skip	Yellow CL
1	179	249	116
2	252	280	113
3	280	271	121
4	263	-----	152
5	278	-----	185
Average	**250**	**267**	**137**
Standard Dev.	42	16	31
Test Site 5 - MM 137.75	White EL	White Skip	Yellow CL
1	212	249	201
2	270	199	211
3	267	241	219
4	252	-----	213
5	302	-----	203
Average	**261**	**230**	**209**
Standard Dev.	33	27	7

Table 2 – Initial Retroreflectivity Readings

In examining the data sets provided in Table 2, roughly 58% of the readings were found to be below the minimum standards of ASTM D 6359. This trend increases from the white edge lines through the yellow centerline with roughly 36% and 72% of the readings below compliance, respectively. As stated previously, the white edge lines were placed on October 22^{nd} while the white skip and yellow centerlines were applied on the following day, October 23^{rd}. It can be assumed the markings were applied in the southbound direction along with the flow of traffic. As shown on October 22^{nd}, it appears that the retroreflectivity readings increase with decreasing mile markers. This may be a function of ambient and roadway surface conditions as the temperatures continued to increase while the percent humidity decreased allowing for a reduction in cure time and an increase in bond strength. This trend does not appear as evident on October 23^{rd}. However, the exact sequence of stripping is unknown. Standard deviations are relatively low indicating consistency of application techniques and associated materials. Standard deviations were found to increase with increasing retroreflectivity levels as would be expected.

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.

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 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 4, as shown below, 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 - Sheffield: White Line Retroreflectivity Averages (mcdl/m2/lux)			
Date	Elapsed Time (Days)	WEL	SKIP
11/5/2002	14	264	208
3/18/2003	147	90	70
5/15/2003	205	106	83
6/26/2003	247	103	79
8/8/2003	290	73	67
8/20/2003	302	114	88
9/15/2003	328	115	111
11/17/2003	391	50	66
12/5/2003	409	263.4*	193.2*
3/24/2004	519	50	40
4/29/2004	555	81	65
5/25/2004	581	85	70
7/29/2004	646	101	86
8/17/2004	665	92	78
10/13/2004	722	105	92
2/7/2005	839	43	43
3/30/2005	890	57	61
6/7/2005	959	78	88
2/9/2006	1206	38	48

* elevated reading

Table 4 – Retroreflectivity Summary for White Edge Line

As anticipated, a significant drop in retroreflectivity, 156 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. In general, the markings continuously decay over time although there does appear to be a spike in December of 2003, one year following installation Given the lower readings prior to and following this particular data collection event, the spike may have been caused by salt residue on the surface of the markings. In addition, while the retroreflectivity readings displayed a large loss following the first winter season and throughout this investigation, the durability readings remained high. This indicates that the epoxy binder was highly resistant to wear from tire abrasion and winter maintenance practices furtherer supporting a problem with the application of glass beads. This may be caused by a number of factors including bead rate, the position sprayer in relation to the binder and/or insufficient ambient and roadway temperatures. Figures 3 and 4 display the condition of the binder in 2003 as compared to 2006, three years following application.

Figure 3 – Test Site 1 (2003)
Durability =10

Figure 4 – Test Site 1 (2006)
Durability = 9

YELLOW CENTERLINE

A similar analysis was performed with the yellow pavement markings with a minimum acceptable retroreflectivity of 65 mcdl as displayed in Table 5.

Lyndon - Sheffield: Yellow Line Retroreflectivity Averages (mcdl/m2/lux)		
Date	Elapsed Time (Days)	YEL
2-Nov	14	155
3-Mar	147	60
3-May	205	63
3-Jun	247	61
3-Aug	290	42
3-Aug	302	63
3-Sep	328	64
3-Nov	391	80
3-Dec	409	133*
4-Mar	519	36
4-Apr	555	45
4-May	581	43
4-Jul	646	47
4-Aug	665	43
4-Oct	722	46
5-Feb	839	33
5-Mar	890	37
5-Jun	959	33
6-Feb	1206	26

*elevated reading

Table 5 – Retroreflectivity Summary for Yellow Edge Line

Once again, a significant drop in retroreflectivity, 95 mcdl on average, is evident following the first winter season. This indicates a substantial initial decay rate of 61%. The retroreflectivity continues to decay over time residing below the FHWA recommendation several months following application with greater losses during winter seasons and a slight rebound during summer months. Once again, the epoxy binder held up well in terms of durability and resistance to wear as shown in Figure 5 and 6 below. As stated previously, wear readings suggest a strong bond to the underlying pavement while the retroreflectivity readings indicate a weak bond to the epoxy binder.

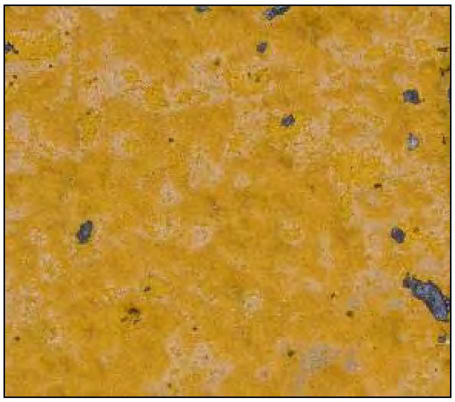

Figure 5 – Test Site 1, 2003
Durability =10

Figure 6 – Test Site 2, 2006
Durability = 7

SERVICE LIFE

Service life estimates for the white line pavement marking could not be determined from Table 4 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 100 mcdl, as shown in Figure 7. Please note that only white lines are modeled for this analysis due to the inherent variability of yellow pavement markings. Unfortunately, a control section comprised of a standard marking material was not incorporated into this study. However, a recent investigation, entitled "Pavement Marking Durability – Statewide," was recently published concerning the overall durability and retroreflectivity of various durable markings. Decay models, incorporating data from various construction projects throughout the state of Vermont, were generated. Figure 7 contains a scatter plot of the epoxy markings as well as a decay model for the white thermoplastic markings for comparative purposes.

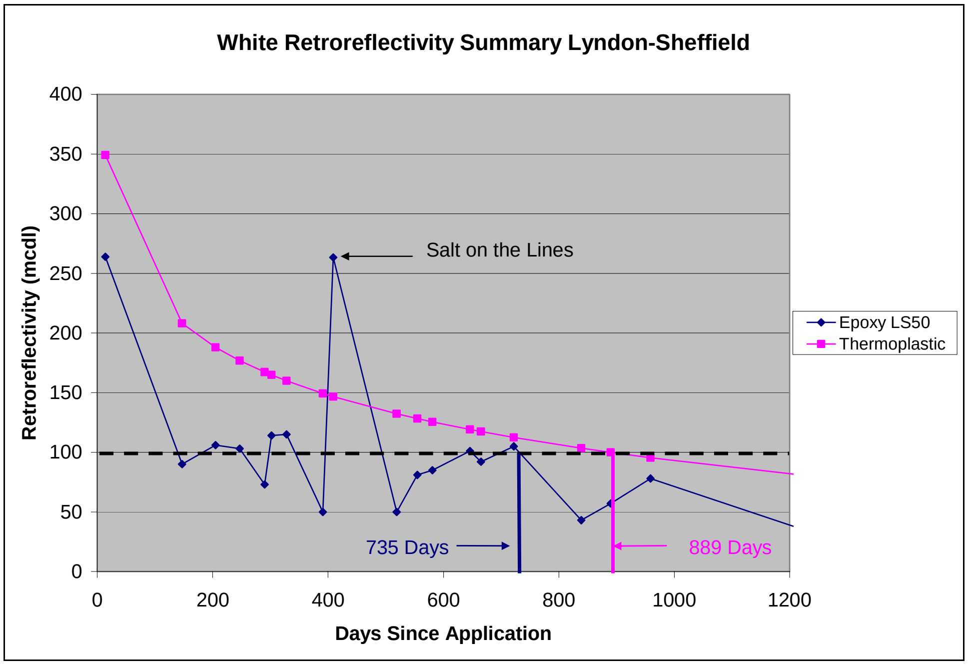

Figure 7 – Epoxy White Edge Lines vs. Thermoplastic Model

Estimated service lives for the white pavement markings are as follows:

- Epoplex LS50 – 735 days
- Thermoplastic – 889 days

COST ANALYSIS:

All costs for the application of the epoxy markings were paid as a part of the Lyndon-Sheffield construction project. In accordance with historic bid information, the application cost for the epoxy markings was roughly $0.24/LF including materials and labor. Additionally, in 2002, the cost for the marking material as reported by the manufacturer was $17.00/gallon which should cover approximately 150 LF for a six inch line at a wet mil thickness of 20 resulting in a material cost of roughly $0.11/LF. However, this price has likely increased over the past five years. The cost per month for each marking was calculated by dividing the total cost of application per linear foot by the estimate service lives in months.

Lyndon-Sheffield Cost Analysis				
	Elapsed Time		Cost	
Material	Days	Months	($/LF)	Cost/Month
Epoplex LS50	735	25	0.24	$0.01
Thermoplastic	889	30	0.37	$0.01

Table 6 – Cost Estimate for Epoxy vs. Thermoplastic Model

Both the epoxy and thermoplastic markings were found to have comparable costs in terms of applicable service life as defined by a minimum threshold for retroreflectivity. However, according to a decay model, thermoplastic provides an additional 5 months of service as compared to the epoxy markings. Additional considerations include the specialized equipment needed to apply the epoxy in addition to future implications. In accordance with manufacturer's recommendations, epoxy may only be overlaid onto epoxy. Typically, the Agency applies waterborne paint when markings are found to be below acceptable levels in terms of luminance and wear. However, waterborne markings may not adhere to the smooth surface of epoxy at which time grinding would be required to remove the preexisting epoxy markings. This would have additional cost implications that were not reflected in the cost analysis.

FINDINGS / SUMMARY:

In an effort to increase the service lives of durable pavement markings while maintaining acceptable visibility, the Vermont Agency of Transportation applied an experimental durable pavement marking, known at Epoplex LS50, to a newly constructed paving project located in the southbound lane of Interstate 91 between the towns of Lyndon and Sheffield in the fall of 2002. It is important to note that the epoxy markings were installed below recommended atmospheric and surface temperatures in addition to a moderately high level of humidity potentially resulting in water condensation on the surface of the pavement. This would increase curing times likely resulting in inadequate adhesion of the marking binder to the surface of the pavement and/or an insufficient bond of the binder to the glass beads.

Following the placement of the markings, data collection, including retroreflectivity and wear readings, was conducted using uniform methods. Most of the epoxy markings were not 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. Additionally, a significant drop in retroreflectivity, 156 mcdl on average for the white markings and 95 mcdl on average for the yellow markings, was evident following the first winter season. This drop was most likely the result of shearing effects produced by winter maintenance practices and may have also been influenced by weather conditions during application. Adherence to the manufacturer's recommendations is recommended for optimum performance. Interestingly, although retroreflectivity readings continued to decline overtime, as would be expected, the wear readings were quite impressive at roughly 8 three and half years following application. This means that approximately 80 percent of the marking binder was intact in 2006.

A cost analysis was performed with consideration to FHWA's minimum recommended retroreflectivity. A decay model of a standard marking, thermoplastic, was also incorporated for comparative purposes. Both the epoxy and thermoplastic markings were found to have comparable costs in terms of applicable service life as defined by a minimum threshold for retroreflectivity. However, according to a decay model, thermoplastic provides an additional 5 months of service as compared to the epoxy markings. In accordance with manufacturer's recommendations, epoxy may only be overlaid onto epoxy. Typically, the Agency applies waterborne paint when markings are found to be below acceptable levels in terms of luminance and wear. However, waterborne markings may not adhere to the smooth surface of epoxy at which time grinding would be required to remove the preexisting epoxy markings. This would have additional cost implications that were not reflected in the cost analysis.

Overall, the application of epoxy is not recommended for high speed locations at this time. The durability of the binder material may make it attractive for lower speed locations or locations with overhead lighting to assist night time visibility. Another investigation may be warranted due to weather conditions during application.

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Appendix A

APPENDIX A - PROTOCOL FOR THE CLEANING OF LINE STRIPPING FOR RETROREFLECTIVE READINGS

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 Reflectometer Testing.