ENHANCEMENTS TO PAVEMENT MARKING TESTING PROCEDURES

Final Report

SPR 681

Oregon Department of Transportation

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by

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16. Abstract

The Oregon Department of Transportation (ODOT) requires performance and durability testing of all pavement marking materials before they can be applied on construction projects on state highways. Manufacturers apply materials on a two-year test deck where the product is evaluated regularly until a determination can be made regarding the suitability of the marking material. If it is determined that the material is suitable, it is included on the Qualified Products List (QPL). The testing and evaluation on ODOT test decks are limited to measuring the thickness of the marking material; assessing dry weather retroreflectivity; and subjective evaluations of appearance and durability. It was determined that a review of pavement marking testing procedures especially those followed in states with climatic conditions similar to Oregon could be useful. The research project includes recommendations to enhance the pavement marking testing and selection process. The recommendations relate to application procedures, monitoring and evaluation, and final selection of products. Proposed minimum retroreflectivity requirements are discussed.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

1.1 BACKGROUND

The driving task is a complex set of actions that must be successfully completed if drivers intend to reach their destination safely. It is imperative then, that the necessary information provided to the driver during the completion of the trip is consistent and beneficial. Pavement markings give this type of information by providing visual cues; such as, appropriate locations to pass, lateral placement of the vehicle (e.g., road center, adjacent lanes, and road edge) and directional indicators, such as left turns ahead. Migletz and Graham (2002) estimate that agencies within the United States and Canada spent more than $1.5 billion on pavement markings in 2000.

Pavement markings are classified as durable markings or waterborne paints. Durable markings offer two advantages: they provide improved visibility during wet-weather nighttime conditions and higher durability for high wear traffic conditions. Durable markings are more expensive, requiring agencies to put measures in place to test and monitor whether longer in-service performance will ultimately be achieved.

Because of the critical nature of striping information, particularly in the context of adverse weather conditions, it is important to understand pavement marking reflectivity during wet weather. During these conditions, a minimum level of retroreflectivity (luminance) is a necessary to support adequate driving performance and to meet the information needs of a diverse population. It is expected that the need for this visual conspicuity will become even more critical as the population ages and has reduced visual acuity. The older driver's diminished eyesight will need to be offset by higher levels of retroreflectivity.

Oregon is one state that experiences a high frequency of wet weather days. Areas like the Willamette Valley experiences rain approximately 40% of the days. The benefits of high reflectivity and the challenges of maintaining highly functioning pavement markings provide the need for this research.

The Oregon Department of Transportation (ODOT) requires performance and durability testing of all pavement marking materials before the materials can be applied on construction projects on state highways. Manufacturers apply materials on a two-year test deck where the product is evaluated until a determination can be made regarding the suitability of the marking material. If it is determined that the material is suitable, it is included on the Qualified Products List (QPL). The testing and evaluation on ODOT test decks are limited to measuring the thickness of the marking material; assessing dry weather retroreflectivity; and subjective evaluations of appearance and durability. Importantly, these tests do not include assessment of wet-weather retroreflectivity or

nighttime wet-weather retroreflectivity. Field tests are not conducted unless particular retroreflectivity concerns are raised that may benefit from further investigation.

This report will cover results from published research that indicate that there is significant variation in (a) the performance of different types of marking materials, (b) different application methods for those materials, and (c) the application patterns used during wet weather conditions and the rates of reduction in luminance under each of the respective conditions listed. In contrast, past research efforts in the area of durable pavement marking materials were inconclusive as to whether initial retroreflectivity is necessarily a good indicator of long-term retroreflectivity performance. Current standards to measure wet-weather nighttime retroreflectivity (such as ASTM E1710) use a 30-m geometry and also use fairly high rainfall intensities that may not be appropriate for prevailing wet-weather conditions.

1.2 OBJECTIVES

The objective of this study was to develop a conceptual framework for the selection of durable pavement markings by incorporating the consideration of retroreflective performance of durable pavement markings during wet weather conditions. The study excluded waterborne paints.

During the first phase of the research, unexpected findings in the literature review indicated that measurement of retroreflectivity under wet weather conditions is particularly difficult (requiring closely monitored laboratory conditions), that wet weather retroreflectivity measurements are often inconsistent and not repeatable. In addition, the release of studies recommending use of raised reflective pavement markings, led to the objectives of the research being adjusted. The initial review of existing ODOT testing procedures indicated shortcomings that may benefit from further consideration.

The revised objectives of the study are:

- To provide for a thorough review of pavement marking testing procedures especially those followed in states with climatic conditions similar to Oregon to identify existing practice and related efforts that could be useful to the ODOT program.
- To make recommendations regarding changes, including consideration of wet weather retroreflectivity, that should be considered to improve ODOT's current pavement marking testing practices.

The revised objectives are geared towards placing ODOT in the best possible position to respond to expected changes in federal standards and to support adjustments in practice based on research and activities already in progress elsewhere in the nation.

In summary, the study offers recommendations to improve the ability of ODOT to make data-driven decisions regarding the provision of durable pavement markings for optimum retroreflectivity performance within given budget constraints.

1.3 ORGANIZATION OF THE REPORT

The organization of this report is as follows: Chapter 1 serves as an introduction to the study and the subsequent chapters. Chapter 2 presents the findings from the literature review including an overview of ongoing federal and state research in the area of wet weather retroreflectivity of durable pavement markings. Chapter 3 discusses current ODOT practice as it relates to the selection of pavement marking materials, specifications for durable pavement markings, and quality control at application on the pavement marking evaluation test site. Chapter 4 presents a summary, conclusions, and recommendations. References and Appendices are provided at the end of the report.

2.0 LITERATURE REVIEW

Chapter 2.0 provides a summary of published literature regarding pavement markings and their associated wet weather retroreflectivity. The chapter consists of several subsections. The chapter presents a general background to pavement markings in Section 2.1, a general background on retroreflectivity in Section 2.2, a more detailed discussion of wet weather retroreflectivity in Section 2.3, testing procedures for durable markings in Section 2.4, results from a recent study of NTPEP test deck results in Section 2.5, the analysis of degradation of durable pavement marking material and retroreflectivity in Section 2.6, the results of state interviews in Section 2.7, and the results from other state-level research in Section 2.8. Section 2.9 is a brief discussion of raised reflective pavement markings within the framework of providing guidance in wet weather nighttime driving environments. Section 2.10 provides a discussion of ongoing and recently completed federal and state research relevant to the ODOT research project and Section 2.11 presents conclusions.

2.1 PAVEMENT MARKINGS

Numerous pavement markings may be used but their visibility and performance varies. This section provides a detailed discussion of these candidate pavement markings. First, this review identifies the purpose of pavement markings. Second, this summary presents and briefly reviews the various pavement marking types. The remainder of this subsection covers other related pavement marking topics including: the service life of pavement markings, factors affecting the visibility of pavement markings, retroreflectivity, the measurement and analysis of retroreflectivity, minimum required retroreflectivity levels, raised reflective pavement markers (RRPMs) and wet-weather retroreflectivity.

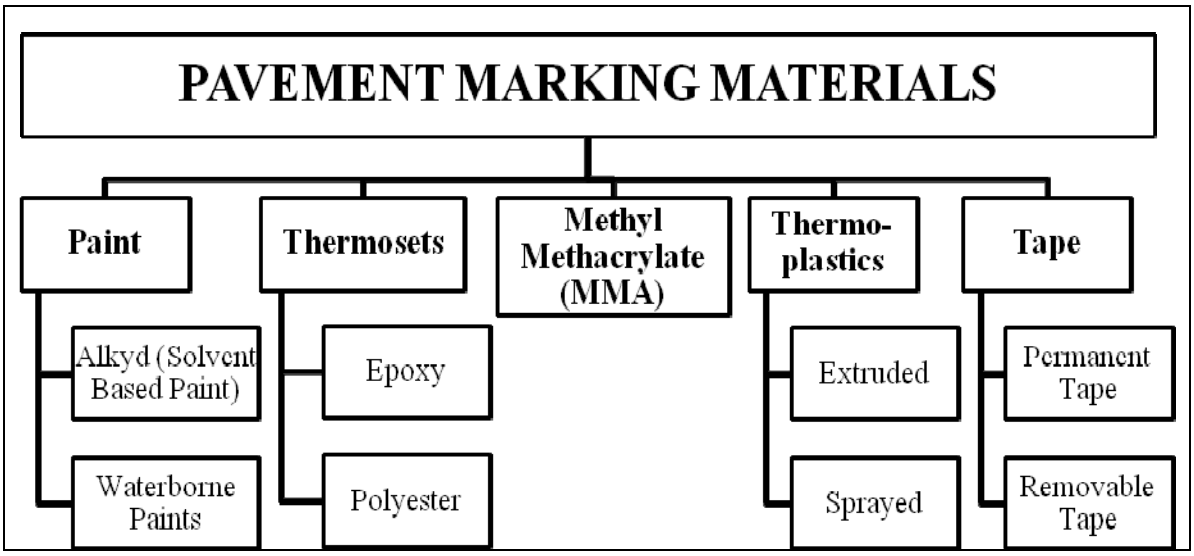
2.1.1 Introduction

Pavement markings are used to delineate roadways (for instance, to identify the division between opposing traffic, different lanes and pavement edges) and to provide horizontal traffic visual cues to road users (markings to indicate turn movements, stop bars, crosswalks, etc.). The markings assist the driver in detecting geometric changes downstream, support passing and merging maneuvers and delineate safe travel boundaries for the driver. These markings play a critical role in the driving task under short, medium and long-range detection distances (*Burns, Hedblom and Miller 2008*).

This study focuses on longitudinal markings. A general discussion of retroreflectivity is covered to provide a basis for a continued discussion of wet-weather retroreflectivity.

2.1.2 Different Types of Pavement Markings

Agencies in the US use several different pavement materials (*Zayed 2009*). Figure 2.1 graphically presents the five different material types currently in use across the US. The focus of this study is on durable pavement markings such as all-weather paint, methyl methacrylate (MMA), and thermoplastics.



Source: (Zayed 2009)

Figure 2.1: Pavement marking material categorization

Durable markings are solvent based paint. In solvent based (alkyd) paint, the polymeric binder creates the film-forming binder with the pavement surface and thus the integrity of the pavement marking. Solvent based paint usually contains calcium carbonate (to extend paint composition), and additives such as anti-skinning agents, anti-settling agents, stabilizers and biocides (*Yu 2004*).

Thermoplastic pavement markings consist of binder, glass beads, titanium dioxide and filler such as carbon carbonate. The beads provide the basic retroreflectivity and the titanium dioxide further enhances the retroreflectivity. The binder holds the different ingredients of the pavement marking together. Thermoplastics can be alkyd or hydrocarbon. Alkyd is a naturally occurring resin that resists oil but that is sensitive to heat while hydrocarbon is produced from petroleum. Thermoplastics require strict quality control measures during installation (*TxDOT 2004*). Thermoplastics are particularly durable on asphalt surfaces but can prematurely fail on concrete surfaces because of poor bonding with the pavement surface (*Gates et al. 2003*).

MMA is a combination of two components that are mixed immediately prior to installation. The first component is a mixture of methyl methacrylate monomer, color pigment, fillers, glass beads, and silica. The second component consists of a benzoyl peroxide that is dissolved in a plasticizer (*Yu 2010*). MMA can be sprayed or applied

with extrusion. MMA is particularly desirable because of the high associated durability in areas affected by cold weather; roadways with high associated traffic volumes (*Gates et al 2003; Thomas and Schloz 2001*); and resistance to materials such as oils, antifreeze and common chemicals. Unfortunately the material is costly, requires a 30-minute curing time and specialized installation equipment (*TxDOT 2004*).

Table 2.1 summarizes the use of different pavement marking materials across State Departments of Transportation (DOTs) (results are from a survey by Markow (*2007*) and data from Migletz and Graham (*2002*) and Hawkins et al. (*2002*).

Table 2.1: Pavement Marking Materials Used by State

LONGITUDINAL PAVEMENT MARKING MATERIAL	NUMBER OF STATES	USING MATERIAL
Water-based Paint	33	89%
Thermoplastic	30	81%
Preformed tape – profiled	20	54%
Preformed tape – flat	19	51%
Epoxy	19	51%
Solvent-based paint	13	35%
Methyl methacrylate	9	24%
Thermoplastic – profiled	9	24%
Polyester	5	14%
Polyurea	2	5%
Cold-applied plastic	1	3%

(Markow 2007)

During a presentation on ODOT's pavement marking program in 2008 at the Northwest Transportation Conference, Ronald Kroop presented the following estimate of the distribution of pavement markings as shown in Table 2.2. During the same presentation Kroop also reported on the status of durable pavement markings across the ODOT regions (shown in Table 2.3). Kroop is an ODOT District Manager and was the chairman of the Statewide Striping Committee at the time.

Table 2.2: Summary of ODOT's Responsibility for Pavement Markings and Markers in Oregon in 2007

REGION	LONG LINE (LINE MILES)	MARKERS (#)	LEGENDS (SQUARE FT)
1	3,769	150,000	242,200
2	7,597	77,000	278,150
3	4,841	230,000	195,123
4	4,996	-	64,284
5	5,488	-	96,133
Totals	26,691	457,000	875,890

(Kroop 2008)

Table 2.3: Summary of Durable Pavement Marking Status by ODOT Region (January 2007)

REGION	TOTAL LINE MILES	MMA	THERMO	TAPE	TOTAL DURABLE (LANE MILES)	%DURABLE
1	3,454	795	765	60	1,620	46.9%
2	6,941	1,052	1,192	2	2,246	33.3%
3	4,826	1,863	1,100	-	2,963	61.4%
4	5,371	255	-	70	325	6.1%
5	5,293	136	30	85	251	4.7%
Totals	25,885	4,101	87	217	7,405	28.6%

(Kroop 2008)

Table 2.4 summarizes the durable pavement markings that are currently in use by ODOT.

Table 2.4: Durable Pavement Markings in use by ODOT

MAJOR CATEGORY	MINOR CATEGORY	APPLICATION METHOD	PRODUCT TYPE
Longitudinal Durable Pavement Markings	Longitudinal Profile	Method A – Profiled	• Methyl Methacrylate, (MMA) Profile, 90 Mils w/ ½" bumps • Methyl Methacrylate, (MMA) Profile, 120 Mils w/ ½" bumps • Thermoplastic, Profile, 90 Mils w/ ½" bumps • Thermoplastic, Profile, 120 Mils w/ ½" bumps
		Method B - Non-Profiled	• Methyl Methacrylate, (MMA) Non-Profile 90 Mils, Extruded • Methyl Methacrylate, (MMA) Non-Profile 120 Mils, Extruded • Thermoplastic, Non-Profile 90 Mils, Extruded Thermoplastic, Non-Profile 120 Mils, Extruded
		Method C** – Protected Inlay	• Flat Line Flat Line – Wet Weather • Truncated Dome • Inverted Profile • Longitudinal Profile
		Method D** - Profiled Wet Weather	• Truncated Dome • Inverted Profile
		Method E** - Non-Profiled Wet Weather	• Flat Line Truncated Dome • Inverted Profile • Longitudinal Profile
		**Options for Methods C, D, & E	• Option 1 -Methyl Methacrylate (MMA) • Option 2 – Thermoplastic
		Method F – Spray	• Methyl Methacrylate (MMA) Spray 90 Mils – Spray • Methyl Methacrylate (MMA) Spray 120 Mils – Spray • Thermoplastic Spray 90 Mils – Spray • Thermoplastic Spray 120 Mils – Spray

MAJOR CATEGORY	MINOR CATEGORY	APPLICATION METHOD	PRODUCT TYPE
		Method G - Tape	• Pavement Marking Tape – Non-Patterned Hot Laid • Pavement Marking Tape – Patterned - Hot Laid • Pavement Marking Tape – Non-Patterned Grooved • Pavement Marking Tape – Patterned – Grooved • Pavement Marking Tape – Wet Weather Pattern, Hot Laid Pavement Marking Tape – Wet Weather Pattern, Grooved
	Longitudinal High Performance Pavement Markings	Method 1 - Spray	Modified Urethane, 25 mils, Spray 00866.00
		Method 2 -Inlaid	Modified Urethane, Protected Inlaid
Transverse Durable Pavement Markings		Type A	Liquid Hot Poured Thermoplastic with intermixed and top-dressed beads, 120 Mils
		Type B	Preformed Fused Thermoplastic with intermixed beads, 125 Mils
		Type B-HS	Preformed Fused Thermoplastic with intermixed beads, 125 Mils (Has better skid performance)
		Type C	Not Used
		Type C-HS	Not Used
		Type D	Methyl Methacrylate with intermixed aggregate & intermixed & top-dressed beads 120 Mils

(*ODOT 2009a*)
Notes: A moratorium has been in place for MMA projects since 6/06.

According to Cuelho, Stephens and McDonald (*2003*) conventional paint is appropriate in areas where traffic or winter maintenance activities do not result in high levels of wear. Epoxy paints or thermoplastics, on the other hand, provide durability on highways in areas experiencing snow and locations of high traffic wear, such as intersections. They also pointed out that the service life of pavement markings is usually strongly correlated with the material cost of the particular marking and this is a critical input element in the asset management of pavement markings.

Measurement of color and retroreflectivity provide quantitative measures while durability is a subjective assessment. Findings indicate that the service life of pavement markings is quite variable. Markow (*2008*) summarized results from a 39-state survey and determined that states reported different service life estimates across thermoplastics and epoxy, that the estimates were often counterintuitive and that the use and wear of pavement markings was not dependent on geographic regions (with different associated weather conditions).

This corresponds to findings from Migletz et al. (*1999*) that showed that the estimation of the service life of pavement markings are difficult and can vary substantially.

Table 2.5 and Table 2.6 summarize the results from research about service life of pavement markings by Markow (*2008*) and Migletz et al. (*1999*) respectively. The variances in estimates of pavement marking service life present challenges when considering effective asset management strategies for pavement markings (*Markow 2008*).

Table 2.5: Estimated Service Life of Pavement Marking Components

COMPONENT AND MATERIAL	NUMBER OF RESPONSES	MINIMUM (YEARS)	MAXIMUM (YEARS)	MEAN (YEARS)	MEDIAN (YEARS)	MODE (YEARS)
Lane and Edge Striping						
Non-epoxy paint	22	0.5	2	1.1	1	1
Epoxy paint	13	1	5	3.3	4	4
Thermoplastic	16	2	10	4.2	4	5
Cold plastic	8	1	10	4.9	5	6
Polyester	2	2	3	2.3	2.3	-
Tape	5	5	10	6.3	6	5
Thin thermoplastic	1	-	-	1-2	-	-
Preformed thermoplastic	1	-	-	3	-	-
Pavement Markers						
Ceramic pavement markers	2	3	3	3	3	3
Raised pavement markers	10	1	5	3.2	3	3
Recessed pavement markers	6	1	5	3.2	2.5	2
Raised snowplowable markers	1	-	-	4	-	-
Other Pavement Markings						
Non-epoxy paint	14	0.5	2	1.1	1	1
Epoxy paint	8	2	5	3.4	3.8	4
Thermoplastic	15	1	10	3.6	3.5	4
Cold plastic	9	1	7	4	4	5
Polyester	2	2	2.5	2.3	2.3	-
Tape	3	2	6	4.2	4	-
Preformed thermoplastic	3	3	5	3.7	4	4

(Markow 2008)

NOTE: - indicates value is undefined for the particular distribution. When distribution is based on only one data point, the value is shown in the mean column.

Table 2.6: Estimated Service Life for White Lines on Freeways

Pavement Marking Material	Number of Pavement Marking Lines	Average Service Life, Months (years)	Range of Service Life, Months (years)
Thermoplastic	14	22.6 (1.9)	7.4 – 49.7 (0.6 – 4.1)
Polyester	2	20.8 (1.7)	14.7 – 27.0 (1.2 – 2.3)
Profiled tape	5	19.6 (1.6)	11.7 – 27.3 (1.0 – 2.3)
Profiled thermoplastic	7	18.4 (1.5)	4.7 – 35.6 (0.4 – 0.3)
Profiled poly (methyl methacrylate)	6	14.0 (1.2)	7.8 – 33.5 (0.7 – 2.8)
Epoxy	11	12.8 (1.1)	3.4 – 34.0 (0.3 – 2.8)
Poly (methyl methacrylate)	6	11.9 (1.0)	6.8 – 17.5 (0.6 – 1.5)
Water-based paint	3	10.4 (0.9)	4.1 – 18.4 (0.3 – 1.5)

Source: (Migletz et al. 1999)

2.1.3 Factors Affecting the Visibility of Pavement Markings

Figure 2.2 summarizes the visibility of pavement markings. Table 2.5 provides further detail on each of these factors and how each factor impacts visibility. The different factors can be categorized as driver, pavement, environment, roadway, pavement marking, policy, or vehicle-related. A state DOT typically can only impact human factor related aspects (designing for adequate preview time, etc.); policies related to winter snow removal and studded tire use; and the selection, installation, and maintenance of pavement marking materials to support adequate visibility of pavement markings.

Table 2.5 also provides the typical values used in the TarVIP models. TarVIP is a software tool used in a variety of human factor applications. For example, the tool can be used to determine the "approximate detection distances for pavement markings" (*University of Iowa 2004*).

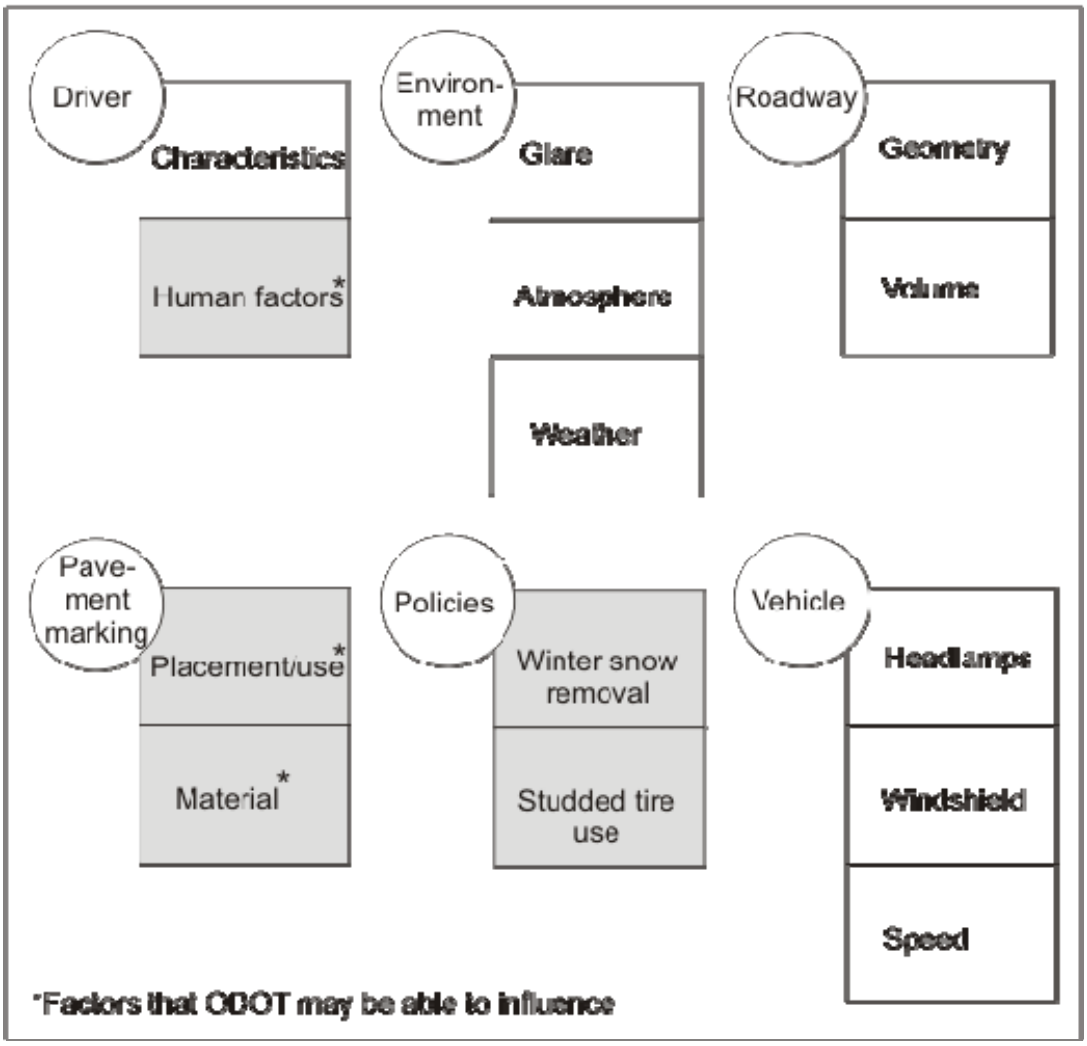


Figure 2.2: Summary of factors that may affect the visibility of pavement markings

Table 2.5: Factors that can impact pavement marking condition, visibility and retroreflectivity

CATEGORY	FACTOR	NOTES	TarVIP MODEL VARIABLES FOR MINIMUM RETROREFLECTIVITY (*Carlson, Miles, Pike, & Park, 2007*)	REFERENCES
Driver	Driver age	In general minimum pavement marking retroreflectivity values are set for older driver needs (Debalilon and Carlson *2007*).	62 (held constant in the analysis)	Zwahlen and Schnell (*1999*); Carlson, et al. (*2007*);
	Driver attention		Full attention	He, et al. (*2006*)
	Driver workload		Driver not distracted and low workload	He, et al. (*2006*)
Driver characteristics and vehicle	Driver eye location as a function of the observer gender and vehicle class			Zwahlen and Schnell (*1999*)
Driving environment	Highway type	Shahata et al. (*2008*) distinguished between highways, arterial roads, secondary streets, and collectors.		Shahata, et al. (*2008*)
	Overhead lighting		No overhead lighting	Ethen and Woltman (*1986*)
Environment	Atmospheric transmissivity		0.86/km	Zwahlen and Schnell (*1999*); He, et al. (*2006*)
	Horizon sky luminance			Zwahlen and Schnell (*1999*); He, et al. (*2006*)
Geometry	Geometric conditions	Curves	The analysis only included straight roadways	Kopf (*2004*)
	Geometric conditions	Weaving areas		
Geometry	Location of the marking line • Center line • Left Line • Right Line		Three levels of pavement marking configurations: • Yellow dashed centerline with white edge lines • Yellow dashed centerline • White left lane line.	Shahata, et al. (*2008*)

CATEGORY	FACTOR	NOTES	TarVIP MODEL VARIABLES FOR MINIMUM RETROREFLECTIVITY (*Carlson, Miles, Pike, & Park, 2007*)	REFERENCES
	Number of lanes			Shahata, et al. (*2008*)
	Presence of overhead roadway			Published literature not available on this topic
	Use of edge lines in addition to center lines	Minimum required retroreflectivity R_L is lower for a fully-marked roadway compared to a roadway with only a centerline.[1] The minimum R_L is reduced by 66% when a solid white edge line is provided with a dashed yellow centerline rather than a dashed white lane line at 40 mph (reduction of 85% for 70 mph) (*Debaillon, et al. 2008*).	One option included a yellow dashed centerline with white edge lines	Zwahlen and Schnell (*1997*)
	Cross slope	Little or no cross slope reduces retroreflectivity,		Carlson, et al. (*2007*)
Legislation	Legislation	Studded tires allowed (and region or likely routes to be served by these vehicles)		Published literature is not available on this topic
Pavement	Pavement surface age	Date since last pavement overlay	Old asphalt and old concrete pavement surfaces	Shahata, et al. (*2008*); He, et al. (*2006*)
Pavement	Pavement surface condition	Shahata, et al. (*2008*) used a scale of 1 through 5 with 1 being 'very poor' and 5 'excellent'.		Shahata, et al. (*2008*); He, et al. (*2006*)

[1] The Coefficient of Retroreflected Luminance (R_L) is the most common measurement used for retroreflectivity of pavement markings. The R_L is defined as "the ratio of the luminance of a projected surface of retroreflective material to the normal illuminance at the surface on a plane normal to the incident light" (Austin and Schultz 2002).

CATEGORY	FACTOR	NOTES	TarVIP MODEL VARIABLES FOR MINIMUM RETROREFLECTIVITY (*Carlson, Miles, Pike, & Park, 2007*)	REFERENCES
	Pavement surface material.	• Asphalt • Concrete. pavement markings are more visible on old concrete than on old asphalt (*Schnell, Zwahlen and Smith 1999*)	Old asphalt and old concrete pavement surfaces	Andrady (*1997*); Schnell, Zwahlen and Smith (*1999*); Debaillon, et al. (*2008*)
Pavement Marking	Available retroreflective area in pavement marking			He, et al. (*2006*)
	Degree of Obliteration		None	Published literature is not available on this topic
	Center line configuration pavement marking configuration		10-ft (3.048 m) skip with 30-ft (9.144 m) gaps	He, et al. (*2006*)
	Lateral separation between double lines		No double lines	He, et al. (*2006*)
	Pavement Marking Material Type	Shahata, et al. (*2008*) distinguished between water borne, Alkyd, Epoxy, and Others	Alkyd paint with AASHTO M247 glass beads.	Shahata, et al. (*2008*); He, et al. (*2006*)

CATEGORY	FACTOR	NOTES	TarVIP MODEL VARIABLES FOR MINIMUM RETROREFLECTIVITY (*Carlson, Miles, Pike, & Park, 2007*)	REFERENCES
Pavement Marking Placement/Use	Pavement Marking Width	Increase dashed center line width from 0.16-ft (0.049 m) to 0.3 ft (0.091 m) results in a 6.6% increase in average end detection distance; and increase in single solid center line width from 0.16-ft (0.049 m) to 0.3 ft (0.091 m) results in a 47% increase in average end detection distance (*TxDOT 2003*)	4-inches	Cottrell (*1986*); Hall (*1987*); Zwahlen and Schnell (*1997*); Migletz, et al. (*1999*); Gates and Hawkins (*2002a*); Carlson, et al. (*2005*); Gibbons, McElheny and Edwards (*2006)*; Carlson, et al. (*2007*)
	Solid lines and dashed lines	Debaillon et al. (*2007*) found that the use of a solid line allows for a reduction in the minimum required retroreflectivity values. They hypothesize that this may be because of the greater proportional area that is illuminated by the headlamp further away from the vehicle.		
Pavement Marking Material	Date since application (age)			Shahata, et al. (*2008*)
	Retroreflectivity			Finley, et al. (*2002*); Debaillon and Carlson (*2007*).
	Color	White markings have a higher retroreflectivity than yellow markings (*Thomas and Schloz 2001*)		Thomas and Schloz (2001)
Policies and Weather	Winter snow removal practices: Abrasives	Shahata, et al. (*2008*) included the amount of abrasives used per km.		Shahata, et al. (*2008*)
	Winter snow removal practices: Salt	Shahata, et al. (*2008*) included the amount of normalized salt used per km.		Shahata, et al. (*2008*)

CATEGORY	FACTOR	NOTES	TarVIP MODEL VARIABLES FOR MINIMUM RETROREFLECTIVITY (*Carlson, Miles, Pike, & Park, 2007*)	REFERENCES
Policies and Weather	Winter snow removal practices: Snowplows	Bit type of snowplow used		
	Winter snow removal practices: when snow removal process starts relative to first snowfall or amount of accumulation allowed before removal starts	Frequency of snow removal on particular route/ number of snow removals in a particular year on a particular route		
Raised Reflective Pavement Markers	Presence of raised pavement markers	Average detection distances for RRPMs in good condition is more than 550-ft (167.64 m) (*Debaillon and Carlson 2007*).	Carlson, et al. (*2007*) notes that TarVIP does not provide for the inclusion of presence of RRPMs as a measure or to evaluate relative efficiency of two pavement marking materials at the same location.	Zwahlen and Park (*1995*); Zwahlen and Schnell (*1997*); Molino, et al. (*2003*); Molino, et al. (*2004*); Carlson et al. (*2005*); Bahar et al. (*2004*); Debalilon and Carlson (*2007*); Debaillon, et al. (*2008*).
Roadway Conditions, weather, and geometry	Observation time			Zwahlen and Schnell (*1999*)

CATEGORY	FACTOR	NOTES	TarVIP MODEL VARIABLES FOR MINIMUM RETROREFLECTIVITY (*Carlson, Miles, Pike, & Park, 2007*)	REFERENCES
Roadway geometry	Minimum preview time	Preview time is necessary to provide adequate distance for the driver in order to receive information for safe negotiation of the vehicle (*Debaillon and Carlson 2007*). Freedman, et al. (*1988*) recommends 3-sec for long-range guidance preview time and 2-sec for negotiation in adverse weather conditions.	2.2 seconds	Freedman, et al. (*1988*); Zwahlen and Schnell (*1999*); Requirements for Horizontal Road Marking (*1999*); Debalilon and Carlson (*2007*).
	Pavement marking configuration		Three levels of pavement marking configurations: • Yellow dashed centerline with white edge lines • Yellow dashed centerline • White left lane line	Debaillon, et al. (*2008*)
Roadway geometry and driver characteristics	Probability of detection			Zwahlen and Schnell (*1999*)
Traffic	Annual Average Daily Traffic (AADT)	Shahata, et al. (*2008*) reviewed roadways with AADT from 40-100,000 AADT		Shahata, et al. (*2008*)
Traffic/ Driving Environment	Glare from oncoming vehicles	Higher retroreflectivity is necessary in the presence of glare (*Adrian 1989*)	No oncoming vehicle glare.	He, et al. (*2006*)
Vehicle	Beam patterns of the vehicle headlamp		UMTRI-2004 (University of Michigan Transportation Research Institute), 50% low beam	

CATEGORY	FACTOR	NOTES	TarVIP MODEL VARIABLES FOR MINIMUM RETROREFLECTIVITY (*Carlson, Miles, Pike, & Park, 2007*)	REFERENCES
	Headlamp characteristics in terms of candlepower output and efficiency	Improvements in headlamp design generally improve visibility of pavement markings (*Debaillon and Carlson 2007*).	UMTRI-2004 (University of Michigan Transportation Research Institute), 50% low beam. Assumes that headlamps are in good working condition	Uding (*1993*); Carlson and Hawkins (*2003)*; Paniati and Mace (*1993*); Schoettle, et al. (*2004*)
	Vehicle type negotiating the roadway	The average detection distance for the driver of a passenger vehicle is significantly shorter than for a driver of a semi-truck (*Debaillon and Carlson 2007*).	• Passenger sedan • Commercial truck	Rumar, Sivak and Traube (*1999*); Gibbons, Andersen and Hankey (*2005*); Gibbons, McElheny and Edwards (*2006*); Debalilon and Carlson (*2007*); Debaillon, et al. (*2008*)
	Windshield transmission (extent of transmission of light through the windshield)		0.7 (assumes clean windshield).	Zwahlen and Schnell (*1999*); He, et al. (*2006*)
Vehicle and Roadway Conditions	Vehicle speed		• 40 mph • 55 mph • 70 mph	Debaillon, et al. (*2008*)
Weather	Weather conditions	Likelihood of snow or freezing conditions – number of snowy days in the year	Dry conditions	He, et al. (*2006*)

2.2 AN INTRODUCTION TO RETROREFLECTIVITY

Retroreflectivity makes pavement markings visible to drivers at night. Measurement of retroreflectivity assesses the ability of an object to reflect light to a source in the same direction from which the light originally struck the object (*Debaillon and Carlson 2007*).

The retroreflective visual performance of a particular pavement marking is dependent on the structure, binder, and optics of the pavement marking materials. Spherical glass beads are embedded into the diffuse pavement marking material surface. When light from the vehicle headlamp enters the active aperture of the lens, it focuses on the back of the lens. The light strikes the diffuse reflective material coating where it is partially absorbed, scattered, or diffusely reflected back into the lens. A small part of the light reflected back into the lens also reflects back into the direction of the light source. According to Burns, Hedblom, and Miller (*2008*) the size and refractive index of the spherical lenses are the main determinants of pavement marking retroreflectivity.

The glass beads used in pavement markings have a particular reflective index (RI) value. Glass beads with an RI of 1.5 to 1.9 are commonly used. The higher the RI the more expensive and less durable the bead becomes. However, higher RI values are more preferable in wet weather conditions. In continuous wetting conditions, smaller beads will have shorter detection distances. When beads are placed in rumble stripes, the larger beads do not appear to provide longer detection distances (*Carlson et al. 2007*).

According to Burns, Hedblom and Miller (*2008*) the embedment of the bead can also affect retroreflectivity values because the bead has to be embedded in such a way that the diffuse reflective coating covers the focal point of the lens of the bead. This implies that a 1.5 RI bead has to be embedded approximately 60% of its diameter and a 1.9 RI bead has to be embedded to at least 50% to perform well. Burns, Hedblom and Miller (*2008*) estimate that only 30% of beads in conventional "beads-on-paint" systems are actually embedded in the surface and thus exposed to headlights. They also noted that the remaining 70% are completely buried in the pavement marking paint. Manufacturers often coat larger beads to achieve the necessary bead embedment depth. The coating prevents a portion of the beads from sinking into the paint. Bead retention is also critical for retroreflectivity over time.

Bead application can be affected by a variety of factors such as the rate at which the beads are dropped into the binder material, the speed that the striping truck is traveling, the temperature of the pavement marking material and the surrounding environment, and the viscosity of the binder material (*TxDOT 2004*).

Over time, pavement markings deteriorate and loss of retroreflectivity occurs. Developing degradation curves for the retroreflectivity of pavement markings is difficult if not impossible, even with a considerable amount of data (*Kopf 2004*). This degradation is not linear, uniform or gradual and may accelerate with snow removal and extreme environmental factors. Higher initial retroreflectivity does not imply a longer pavement marking service life (S*athyanarayanan, Shankar, and Donnell 2008*).

2.3 WET WEATHER RETROREFLECTIVITY

This subsection presents a discussion of factors affecting wet-weather retroreflectivity and provides background as to whether dry retroreflectivity is a measure of wet-weather retroreflectivity. Section 2.4 covers challenges related to the measurement of wet-weather retroreflectivity.

Edwards (*1999*) found that drivers do not reduce their speeds enough to accommodate for the reduction in breaking distance created by the wet conditions. This is a concern because in wet conditions, the retroreflectivity of the pavement markings is reduced as a result of specular reflection and light refraction. Other factors affecting the wet-weather retroreflectivity include the RI level of the beads in the pavement marking, embedment, and nighttime contrast.

Water affects the effective RI of a pavement marking. Initially rain will wet the surface and a continuous water coating forms on top of the marking (*Carlson et al. 2007*). Light refraction reduces the amount of light reflected back to the driver as light refracts when it travels from air (with RI of 1.0) to water (with an RI of 1.33) (*Burns, Hedblom and Miller 2008*). When the beads become flooded and covered, specular reflection becomes a concern.

Specular reflection occurs when the water smoothes out the pavement surface and light reflects away from the light source. A similar condition occurs when sunlight shines on the pavement surface when it is wet (*Carlson et al. 2007*). Profiled pavement markings may become "virtually invisible" because of specular reflection when the driver is driving against the sun (*COST 331 1999*). This is likely why Carlson et al. (*2007*) observed a significant reduction in retroreflectivity of markings on a roadway with little or no cross slope.

A 1.5 RI bead flooded with water performs as if it were a 1.1 RI bead. When covered, a 1.9 RI bead will behave like a 1.4 RI bead (*Burns, Hedblom and Miller 2008*). Higher RI levels for pavement marking beads are therefore associated with improved performance in wet weather. Beads with RI values of 2.4 to 2.5 provide superior performance in wet weather conditions *(Burns, Hedblom and Miller 2008*). These beads, unfortunately, are more expensive and less durable than the 1.5 RI beads (*Carlson et al. 2007*).

The Coefficient of Retroreflected Luminance (R_L) is the most common measurement used for retroreflectivity of pavement markings. The R_L is defined as "the ratio of the luminance of a projected surface of retroreflective material to the normal illuminance at the surface on a plane normal to the incident light" (*Austin and Schultz 2002*).

Nighttime contrast is also relevant to pavement marking visibility. Nighttime contrast is the difference in R_L values as a portion of the R_L value of the pavement surface itself (*Carlson et al. 2007*). Lane departure rates increase exponentially with a reduction in contrast (*Allen, O'Hanlon and McRuer 1977*).

There is a positive correlation between dry retroreflectivity and detection distance of pavement markings. Unfortunately there are significant differences between the performance of pavement markings in dry and wet conditions (*Carlson et al. 2007*), necessitating the evaluation of retroreflectivity under wet conditions.

The next section provides an overview of relevant ASTM International testing procedures and provides the background and basis for a discussion of the challenges related to the measurement of wet-weather retroreflectivity in Section 2.4.8.

2.4 PAVEMENT MARKING TESTING PROCEDURES

Agencies across the world use ASTM testing procedures as part of their pavement marking material testing procedures. This section discusses these standards and well as the National Transportation Product Evaluation Program (NTPEP).

2.4.1 ASTM Standards and Testing Procedures

ASTM International, formerly known as the American Society for Testing and Materials was established in 1898. ASTM develops international technical standards based on global consensus. Appendix B includes a list of relevant ASTM standards.

Agencies use ASTM D713-90 (*2004*) (see Section 2.4.2), ASTM E1710-05; ASTM E2176-01; and ASTM E2177-01 to assess durable pavement markings. These procedures test the following properties: material related (chemical composition); application thickness, retroreflectivity (daytime dry, daytime wet, and nighttime); tracking (the likelihood that the material will transfer to other positions when traversed by a vehicle); durability; appearance; and useful length of life.

This literature review provides a brief overview of ASTM D713-90 (Reapproved 2004) – Standard Practice for Conducting Road Service Tests on Fluid Traffic Marking Materials and, in Section 2.4.10, relevant testing standards related to wet weather retroreflectivity testing.

2.4.2 ASTM D 713-90 (Reapproved 2004)

ASTM D 713-90 (*2004*) provides a procedure to establish relative service life of pavement marking materials (such as paint, thermoplastic, epoxy, and polyester products) under actual traffic conditions with the use of transverse test lines. Figure 2.3 summarizes the different elements of ASTM D713-90 (*2004*).

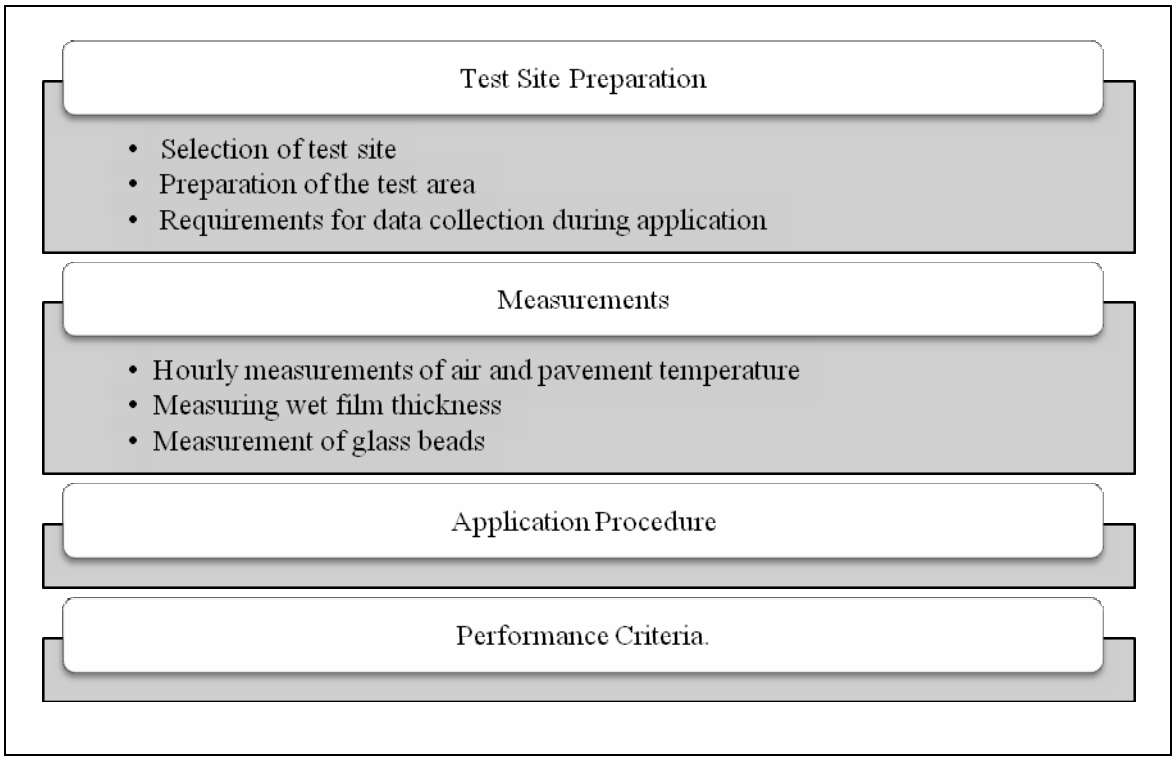


Figure 2.3: Summary of Elements of ASTM D 713-90 (Reapproved 2004)

The requirements for the selection of the test site are of particular interest: the standard requires the selection of a site where "traffic is moderate and free-rolling with no grades, curves, intersections, or access points near enough to cause excessive braking or turning movements, where wear is uniform with full exposure to the sun throughout daylight hours, and there is good drainage. Select surfaces that are representative of the pavements upon which the … material will be used in practice." ASTM D713-90 (*2004*).

The visibility of pavement markings are affected by numerous factors (as summarized in Section 2.1.3), one of which is snow removal practices.

ASTM D713-90 (*2004*) lists a number of performance criteria, including:

- Appearance from 10 feet (color comparison, dirt collection, etc.);
- Durability measured as 1/10th of the percentages of material remaining on the pavement;
- Night visibility measured from the roadside with tungsten illumination); and
- Length of useful life (measured as the number of days from application to date of performance below any of the minimum performance levels for any one or more of the performance criteria).

The test for length of useful life specifies monthly site inspections with visits every two weeks once failure approaches. The assessments required include appearance during the daytime, condition of the pavement marking film, and nighttime retro-reflectance. With these

measurements, the evaluation team can determine cost per foot per day of useful life and the relative performance of the different pavement marking materials on the test bed.

2.4.3 National Transportation Product Evaluation Program Pavement Marking Test Decks

An administrative resolution by the American Association of State Highway and Transportation Officials (AASHTO) Board of Directors led to the founding of the National Transportation Product Evaluation Program (NTPEP) in 1994. NTPEP focuses on prequalification of a range of products including pavement marking materials. Particular emphasis is given to physical testing resources and the use of expertise for dealing with proprietary engineered products.

Annually NTPEP solicits interest for submittal of pavement marking material samples from manufacturers. Participating manufacturers complete application packages from NTPEP and submit payment (calculated using an NTPEP fee schedule). NTPEP reimburses host agencies with NTPEP testing service fees. The testing fees are covered by manufacturers submitting products for evaluation while the administrative fees for the program are covered on a volunteer basis by AASHTO member states.

A project work plan adopted by NTPEP governs how host states conduct and monitor test decks. The project work plan was last revised in August, 2008 and is available online from NTPEP**.** The current project work plan includes field and laboratory tests for pavement marking materials. Raised and recessed pavement markers are not included. Section 2.4.4 discusses the NTPEP project work plan.

Whenever an ASTM International standard is available, the host site uses this standard and reports the results for each of the applications. For pavement marking materials, NTPEP also released a best practices manual referenced as the "NTPEP Best Practices Manual" (BPM). Section 2.4.5 provides a more in-depth discussion of relevant items in the current BPM.

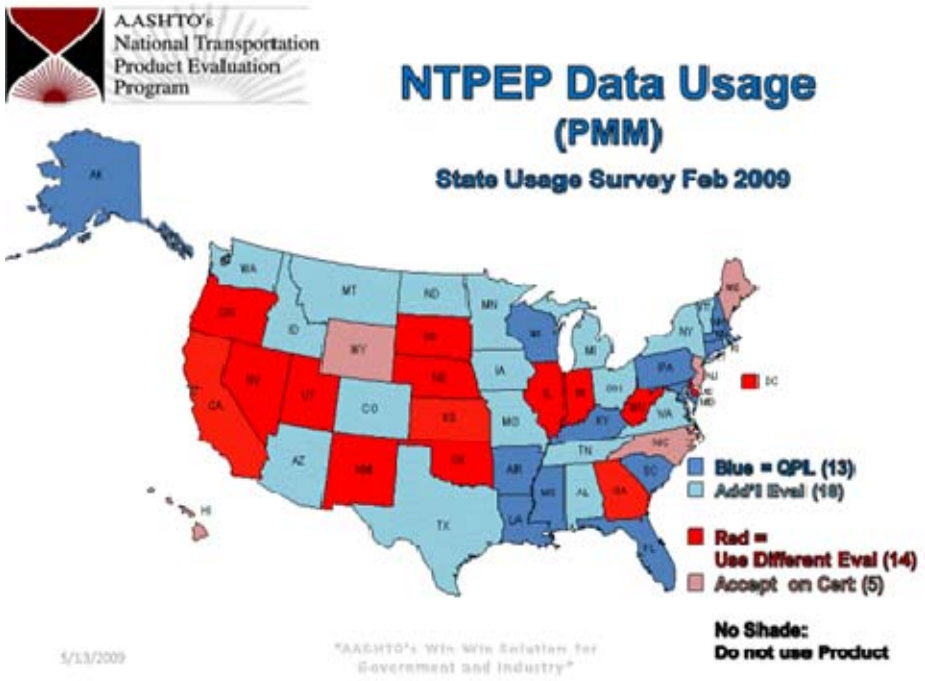
NTPEP develops and provides test deck and laboratory data and reports to AASHTO member states without duty, i.e. each state agency uses the data if, when, and however it meets their needs. NTPEP or host states also do not provide any analysis or recommendations for acceptance of materials to the agencies.

NTPEP selects test deck sites to cover different geo-climatic zones within the US. Since 1995, the following test decks were completed (*NTPEP 2009*):

- California (2000)
- Florida (2009)
- Kentucky (1996)
- Minnesota (1997)
- Mississippi (1999, 2002, 2004, and 2006)
- Oregon (1995)

- Pennsylvania (1996, 1998, 2000, 2002, 2005, and 2008)
- Texas (1996 and 1998)
- Utah (2001, 2005)
- Wisconsin (1999, 2004, and 2007).

Figure 2.4 shows the distribution of states using NTPEP data as of February 2009. This graphic depicts states using the data for developing their QPL; states using NTPEP and additional evaluation criteria for their QPL; states using different evaluation procedures; and states accepting materials based on certification.



(NTPEP 2009)

Figure 2.4: NTPEP Data Usage for Pavement Marking Materials

2.4.4 NTPEP Project Work Plan

The NTPEP Project Work Plan (PWP) is developed through consensus with peer review and incorporates input from industry experts. The PWP does not supersede any state DOT standard specifications.

According to the current Project Work Plan (PWP), NTPEP alternates test sites annually between snowplow and non-snowplow sites. Installations are tested on both portland cement and bituminous concrete surfaces. Each test site has to be exposed to AADT in excess of 5,000 and must remain open to traffic for two years (additional requirements of the test sites are included in the PWP (*NTPEP 2008*).

When a product uses beads other than Type 1 beads or alternative application rates, it is regarded as a system rather than an individual product and is so noted as part of the resulting test deck report. Section 5 in the PWP also restricts the types, systems, and film thickness of applications. Table 2.6 presents the NTPEP pavement marking product criteria and restrictions.

Table 2.6: NTPEP Pavement Marking Product Criteria and Restrictions

MATERIAL	COLORS	FILM THICKNESS	OTHER
Paints	• White • Lead Based Yellow • Non-Lead Based (Organic) Yellow	15 + 1 mil and 4 + ½ inches in width Paints applied at different film thicknesses shall be noted in the original submittal and reported by the host state.	• One of two binder systems – VOC-compliant solvent-borne, water-borne • Three No-Track times – 60 Seconds, 90 Seconds, Three (3) Minutes
Thermoplastics	• White • Lead Based Yellow • Non-Lead Based Yellow	125 $\pm$ 5 mils and 6 $\pm$ ½ inches in width For systems designed for applications less than 125 mils the recommended thickness shall be noted in the original submittal by the manufacturer and reported by the host state.	
Spray Thermoplastics	• White • Lead Based Yellow • Non-Lead Based Yellow	15-35 mils and 4 ± ½ inches width or as manufacturer specified	
Tapes	• White • Lead Based Yellow • Non-Lead Based Yellow	6 $\pm$ ½ inches width with or without primer sealers	

(NTPEP 2008)

2.4.5 NTPEP Best Practices Manual

The current BPM was developed in conjunction with the Utah T2 Center and is available online from NTPEP (*Bolling and Thompson, 2005)* The purpose of this section is to provide a brief overview of relevant items.

The NTPEP BPM covers topics such as contracting and cost; scheduling vendors; work plan and training outlines; sampling; on-site test deck preparation; typical test deck operations; and monthly and quarterly data collection.

The current BPM requires evaluation intervals for installations: an initial evaluation within seven days, approximately every 30 days for the first year, every 120 days for the second year. While mention is made of a third year evaluation, it is noted that the evaluation may not be authorized (*Bolling and Thompson 2005*).

The BPM recommends the use of test deck mapping, i.e. preparation of a spreadsheet mapping of the test deck, specifying the subdeck number, line number, material type, color and specific PMM number; and the use of such a map for recording evaluation readings.

The evaluations in the current BPM cover aspects such as retroreflectivity, wet-night retroreflectivity (if requested by the manufacturer), night color of yellow markings, day color, durability and photo logging. Photo logging is used to identify types of pavement marking failure and field conditions such as debris or dirt. The document outlines the particular position, testing procedure and approach to follow in each of the evaluation categories

The next section discusses the measurement of retroreflectivity, the topic of minimum retroreflectivity, and the measurement of wet weather retroreflectivity in more detail. Where appropriate, reference is made to procedures in ASTM International standards.

2.4.6 Measurement of Retroreflectivity

Retroreflectivity measurement assesses how well pavement markings will perform with headlamp illumination (*Debaillon and Carlson 2007*). Retroreflectivity is measured in millicandelas per square meter per lux (mcd/m^2/lux). Retroreflectivity increases the detection distance of pavement markings. For example, increasing the retroreflectivity of tape from 100 to 800 md/m^2/lux increases the detection distance from 285-ft (86.87 m) to 502-ft (153.01 m) (*Debaillon and Carlson 2007*). The relationship between retroreflectivity and detection distance is not linear.

ASTM International provides standards for the measurement of retroreflectivity under different conditions. According to these standards, retroreflectivity is measured using a standard 30-m (98.4ft) geometry. This represents the view of a driver of a passenger car during adverse weather at nighttime (*Debaillon and Carlson 2007*). Although an approximation, it does not truly represent the view of the average driver who views the roadway at approximately 50 degrees. The 50-degree geometry unfortunately "produces angles that are too flat to measure properly" (*Kopf 2004*).

There is a significant amount of variability among retroreflectivity of markings on highways with similar conditions and daily traffic volumes. Kopf (*2004*) and Markow (*2008*) both comment that the varying conditions during field data collection, variability in retroreflectometers, difficulty in calibrating retroreflectometers, skill level of the individual taking the reading, and repeatability and reliability of field measurements make the measurement of retroreflectivity of pavement markings particularly problematic. The values measured are greatly dependent on the placement and orientation of the retroreflectometer, the color of the markings and its background, and dirt on the lines (*Kopf 2*004).

Research results from Rasdorf, Zhang, and Hummer (*2009*) on paint retroreflectivity suggests that directionality affects retroreflectivity readings. Rasdorf, Zhang, and Hummer (*2009*) found differences in retroreflectivity readings in the direction of paint striping and in the opposite direction. One expects that retroreflectivity readings for profiled durable pavement markings would differ along the line and perpendicular to the line. It has not been established whether retroreflectivity for flat durable pavement markings would differ based on directionality.

The initial thickness of application of thermoplastic pavement markings on newly sealcoated roadway surfaces affects retroreflective performance (*Gates and Hawkins 2002a*). Gates and Hawkins (*2002a*) recommended the use of needlepoint micrometers to TxDOT field inspectors and further recommended that measurements be taken to the top of the binder material rather than to the top of the drop-on beads.

The measurement of retroreflectivity is a critical element in the asset management of pavement markings. Markow (*2008*) conducted a survey of State DOTs and concluded that "the need for more reliable and standardized retroreflectivity measurements was evident." Some of Markow's recommendations towards this end highlight general concerns related to the measurement of retroreflectivity:

- Acceptance of a national standard for calibrating reflectometers;
- Improved understanding of the process necessary to collect consistent, repeatable, and reproducible readings; and
- Establishment of protocols to collect consistent and reliable readings in different conditions, especially those in wet weather.

2.4.7 Minimum Levels of Retroreflectivity

After years of research, FHWA is in the process of initiating minimum retroreflectivity requirements for pavement markings. FHWA commissioned research to support minimum retroreflectivity standards for pavement markings. This subsection includes a summary of the research results and presents the proposed FHWA rule for minimum retroreflectivity levels of longitudinal pavement markings.

Ethen and Woltman (*1986*) first suggested a minimum value of 100 mcd/m^2/lux for pavement marking retroreflectivity after evaluating feedback from participants driving a four-lane freeway. Later Graham and King (*1991*) determined that a minimum level of 93 mcd/m^2/lux is necessary for older drivers. Subsequently, after an additional study, Graham, Harrold and King (*1991*) recommended a level of 100 mcd/m^2/lux after determining that 85% of the participating 59 older drivers in the study rated markings at this level as adequate or better.

Loetterle, Beck and Carlson (*1998*) found that a representative sample of Minnesota drivers rated 100 mcd/m^2/lux as acceptable. In addition, the ratings improved substantially from 0 to 120 mcd/m^2/lux, but less so from 120 to 200 mcd/m^2/lux. In this case, the researchers recommended a minimum level of 120 mcd/m^2/lux for the Minnesota Department of Transportation (MnDOT) pavement marking maintenance program. Parker (*2002*) recommended a minimum value of 130 mcd/m^2/lux to the New Jersey Department of Transportation (NJDOT) after drivers ages 55 and over indicated that the acceptable threshold ranged between 120 and 165 mcd/m^2/lux.

Sathyanarayanan, Shankar and Donnell (*2008*) reviewed minimum retroreflectivity requirements and concluded that the threshold level of pavement marking retroreflectivity is between 70 and 180 mcd/m^2/lux (*King and Graham 1989; Graham and King 1991; Migletz et al. 1999; Loetterle, Beck and Carlson 2000; Parker, Massawe, et al. 2002; Finley et al. 2002; Parker and Meja 2003*).

In the development of federal minimum retroreflectivity requirements for pavement markings, Debaillon et al. (*2008*) built on work by Zwahlen and Schnell. Zwahlen and Schnell (*1997*) developed the first set of recommended minimum levels of retroreflectivity for RRPMs using the Computer-Aided Road-Marking Visibility Evaluator (CARVE) Model. The CARVE model was originally developed by Ohio University for the FHWA in an effort to identify the needs of drivers in terms of pavement markings.

The Target Visibility Predictor (TarVIP) model later replaced the CARVE model. Debaillon et al. (*2008*) used 48 different scenarios in the TarVIP model as part of their study. TarVIP is a newer generation deterministic model that incorporates changes in the materials of pavement markings, vehicle headlamps, and different pavement surface types. It also includes different roadway profiles in the modeling process. Table 2.5 provides default values that the research team used and different scenarios tested as part of the research effort. The researchers concluded that minimum R_L levels are most sensitive to preview time (particularly at higher speeds) – for example, a minimum R_L of 735 mcd/m^2/lux is required for a vehicle traveling 70 mph and a preview time of 4.0 seconds (detection distance of 411-ft (125.273 m)). Table 2.7 shows the recommended minimum R_L levels based on this research.

Table 2.7: Recommended minimum retroreflectivity levels in mcd/m^2/lux

ROADWAY MARKING CONFIGURATION (WHITE AND YELLOW)	WITHOUT RRPMS			WITH RRPMS*
	≤ 50 mph	55-65 mph	≥ 70 mph	
Fully marked roadways (with centerline, lane lines, and edge line, as needed)	40	60	90	40
Roadways with centerlines only	90	250	275	50

(Debaillon, et al. 2008)

* Three RRPMs in good condition should be visible to the driver.

On April 22, 2010, FHWA published proposed rules for minimum retroreflectivity of longitudinal pavement markings as 23 CFR Part 665 in the Federal Register (Volume 75, Number 77, pages 20935-20941). Comments are due by August 20, 2010. The proposed rule amends the 2010 MUTCD by providing for the addition of Section 3A.03. This subsection briefly summarizes the proposed rulemaking.

A FHWA publication titled "Summary of the MUTCD Pavement Marking Retroreflectivity Standard" *(FHWA 2010)* categorizes pavement markings as:

- "*not required to be retroreflective*" – features where ambient illumination would provide sufficient visibility or where the particular markings are only needed during the daytime.
- "*required to be retroreflective, but not subject to minimum levels*" – features such as markings at crosswalks, symbols, arrows, etc. with continuous road lighting or where raised retroreflective pavement markers are present.
- "*subject to minimum retroreflectivity levels*" – required or recommended white and yellow markings in the MUTCD (center lines, edge lines, lane lines, and lines providing channelization) that meet certain criteria in terms of traffic volumes or particular roadway conditions.

Maintaining retroreflectivity during winter months can be particularly challenging. The proposed rulemaking recognizes this difficulty. An agency is considered in compliance if the agency with jurisdiction has a method and uses this method to maintain the markings in accordance with the new Section 3A.03 of the MUTCD.

Table 2.8 (listed as Table 3A-1 in the proposed rulemaking) presents the minimum retroreflectivity requirements for the following longitudinal pavement markings:

- Locations where center line markings are required or recommended in Section 3B.01 (includes longitudinal two-way left-turn lane markings, no passing zone markings, and yellow markings used to delineate flush medians on such facilities)
- Lane line markings required or recommended in Section 3B.04 (includes lane drop markings, dotted lane lines, and preferential longitudinal lane markings)
- Edge line markings required or recommended in Section 3B.07 (pavement markings providing channelization at gores, divergencies, or obstructions)
- Optional edge line markings meeting the requirements for "All other roads" of Table 3A-1.

Table 2.8: Minimum Maintained Retroreflectivity Levels[1] for Longitudinal Pavement Markings (referenced as Table 3A-1 in the proposed rulemaking and subject to revision)

	Posted Speed (mph)		
	≤ 30	**35-50**	**≥ 55**
Two-lane roads with centerline markings only[2]	n/a	100	250
All other roads[2]	n/a	50	100

1. Measured at standard 30-m geometry in units of mcd/m^2/lux
2. Exceptions:
   A. When RRPMs supplement or substitute for a longitudinal line (see Section 3B.13 and 3B.14), minimum pavement marking retroreflectivity levels are not applicable as long as the RRPMs are maintained so that at least 3 are visible from any position along that line during nighttime conditions.
   B. When continuous roadway lighting assures that the markings are visible, minimum pavement marking retroreflectivity levels are not applicable.

The proposed rulemaking presents methods of which one or more should be used to maintain the minimum retroreflectivity levels:

A. "*Calibrated Visual Nighttime Inspection – Prior to conducting a nighttime inspection from a moving vehicle and, in conditions similar to nighttime field conditions, a trained inspector calibrates his eyes to pavement markings with known retroreflectivity levels at or above those in Table 3A-1. Pavement markings identified by the inspector to have retroreflectivity below the minimum levels are replaced.*

B. Consistent Parameters Visual Nighttime Inspection – A trained inspector at least 60 years old conducts a nighttime inspection from a moving vehicle under parameters consistent with the supporting research. Pavement markings identified by the inspector to have retroreflectivity below the minimum levels are replaced.

C. *Measured Retroreflectivity – Pavement marking retroreflectivity is measured using a retroreflectometer. Pavement markings with retroreflectivity levels below the minimums are replaced.*

D. *Service Life Based on Monitored Markings – Markings are replaced based on the monitored performance of similar in-service markings with similar placement characteristics. All pavement markings in a group/area/corridor are replaced when those in the representative monitored control set are near or at minimum retroreflectivity levels. The control set markings are monitored on a regular basis by the visual nighttime inspection method, the measured retroreflectivity method, or both.*

E. *Blanket Replacement – All pavement markings in a group/area/corridor or of a given type are replaced at specific intervals. The replacement interval is based on when the shortest-life material in that group/area/corridor approaches the minimum retroreflectivity level. The interval is also based on historical retroreflectivity data for that group/area/corridor.*

F. *Other Methods – Other methods developed based on engineering studies that determine when markings are to be replaced based on the minimum levels in Table 3A-1."*

FHWA proposes that the minimum retroreflectivity requirements be phased-in over a period of four years from the date of the Final Rule for implementation and continued use of maintenance methods that are geared towards maintaining retroreflectivity at or higher than the set minimum retroreflectivity levels. A six year period is suggested for replacement of those markings not meeting the minimum retroreflectivity levels.

A Summary of the MUTCD Pavement Marking Retroreflectivity Standard (FHWA-SA-10-015) is included as Appendix C.

2.4.8 ASTM Testing Procedures for Retroreflectivity

The following ASTM testing procedures are relevant to testing wet weather retroreflectivity:

- ASTM E1710-05, Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer: specifies the methodology to measure pavement marking retroreflectivity;
- ASTM E2176-01, Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (RL) of Pavement Markings in a Standard Condition of Continuous Wetting: represents retroreflectivity of the pavement marking during rainy conditions; and
- ASTM E2177-01, Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (RL) of Pavement Markings in a Standard Condition of Wetness: represents retroreflectivity of pavement marking after rainwater drained from the marking but the marking.

Agencies can measure RL with a portable retroreflectometer using the ASTM E 1710-05 standard. The 30-meter geometry is still used as part of this standard and the standard specifies testing conditions (ambient temperature, surface condition, etc.), the entrance angle, observation

angle, presentation angle and specifics related to the placement of the retroreflectometer. The standard specifically points out that the observer should ensure that the particular instrument is capable of measuring retroreflectivity for the marking height – this is particularly relevant for profiled markings. Of interest to transverse line test decks, the standard draws attention to the fact that the observer may measure less uniform readings on transverse lines than on longitudinal lines. Other factors affecting the readings are also listed: "slight changes in the position of the retroreflectometer on the traffic line", the RI value of the beads and embedment depth, population of beads on the pavement marking material, the pigment loading of the binder, and materials on the pavement marking surface (dirt, salt, dust, etc.).

ASTM E 2176-01 specifies the measurement standards for wet retroflective R_L properties of pavement markings under continuous wetting conditions. This method specifies use of mobile or portable retroreflectometers. A rain/water shield is specified along with the rain simulator (a water sprayer) and a wetting agent. The method applies water at a rate of 0.8 L/minute with a "minimum capacity, adjustable nozzle garden sprayer".

ASTM E2177-01 specifies the measurement of R_L under a standard condition of wetness, i.e. after rainfall took place and the marking is still wet or if the "marking are wet from morning dew or humidity." With this standard the individual takes readings in both dry and wet conditions, using the dry condition measurement as a bench mark for comparison with the wet weather retroreflectivity measurement. In this case the marking is wetted with a hand sprayer for 30 seconds so it is completely flooded. Alternatively the individual can pour two to five liters of water on the marking. The individual measures the R_L value 45 ± 5 seconds after the spraying of the marking. In this case retroreflectivity is measured in both directions of the marking.

This standard specifically provides a discussion of the impact of the ability of the water to drain from the marking, an aspect affected by inclines and low areas or dips.

2.4.9 Research on ASTM Wet-Weather Retroreflectivity Measurement Procedures and Visibility of Pavement Marking Materials in Wet Weather Nighttime Conditions

This section reviews two topics particularly relevant to wet weather nighttime retroreflectivity: the amount of simulated rainfall in the ASTM wet weather retroreflectivity measurement procedures, and the effect of pavement marking width on wet weather retroreflectivity.

Carlson et al. *(2007)* conducted a 30-month investigation of wet-night pavement markings in Texas. The Texas study also included an evaluation of the presence and performance of other contrast pavement markings (RRPMs in particular). The study compared performance at the more typical rainfall rates for Texas (0.25 in/hr to 0.8 in/hr) to the rates recommended in the ASTM specification and found that the measurements taken for the lower rates were more reliable and provided a more adequate measure of performance than those using the ASTM specifications (9 in/hr). In a study of profiled durable pavement markings Burns, Hedblom and Miller (*2008*) used 0.3 inches per hour rain as a representative wet condition for these markings.

After concluding their 30-month investigation, Carlson, et al. (*2007*) concluded that RRPMs outperformed all other markings in terms of detection distances in wet-nighttime conditions. The researchers recommended the use of RRPMs as wet-night delineation and did not recommend the use of the ASTM requirement for wet weather retroreflectivity as a performance measure. Given the high cost of all-weather markings, the researchers also recommended the use of RRPMs with standard thermoplastic pavement markings as a more cost-effective alternative for wet-nighttime conditions.

2.4.10 Concerns Regarding Existing Testing Procedures

The literature review provided insight into five items that highlight limitations of existing ASTM testing procedures for the retroreflectivity of durable pavement marking materials:

- The use of the 30-m (98.4ft) geometry;
- The use of transverse lines to simulate accelerated wear of longitudinal lines;
- The amount and nature of simulated rainfall in wet weather condition testing;
- The effect of cross slope on retroreflectivity measurements; and
- The impact of application thickness on retroreflectivity.

2.4.10.1 Use of the 30-m (98.4ft) Geometry

Kopf (*2004*) comments that the 30-m (98.4ft) geometry is not a true representation of the view of the average driver and suggests that this geometry may not render results that are representative of the drivers' view. Burns, according to Hedblom and Miller (2008), indicated that the 30-m (98.4ft) R_L value is only sufficient for a 1.5 index glass bead optic on a flat pavement marking and not for profiled pavement marking systems. Durable pavement markings are often profiled.

2.4.10.2 The Use of Transverse Lines to Simulate Accelerated Wear of Longitudinal Lines

The use of transverse lines to test the performance of longitudinal lines could potentially pose challenges in terms of establishing retroreflectivity changes across time. Work by Rasdorf, Zhang, and Hummer (*2009*) (discussed as part of Section 2.4.6) indicates that directionality of measurement affects retroreflectivity measurements for paint pavement markings. It has not been established whether transverse lines accurately simulate accelerated wear of longitudinal lines.

2.4.10.3 Amount of Simulated Rainfall in Wet-Weather Condition Testing

When Carlson, et al. (*2007*) evaluated dry, continuous wetting, and recovery retroreflectivity for a variety of materials, they found their observed results were consistent across different pavement marking types but inconsistent within pavement marking types. Measuring retroreflectivity under continuous wetting conditions appeared to present the biggest challenge. Retroreflectivity values did not necessarily reduce with

higher rainfall intensity because at some intensities the pavement marking became flooded, providing almost no retroreflectivity. In the same study the researchers list the following characteristics that can impact retroreflectivity results:

- Cross slope,
- Flow rate of water,
- Wind,
- Size of droplets,
- Density of droplets,
- Uniformity of sprayed water, and
- Interference with the measuring window of the instrument.

Subsequently, Carlson, et al. *(2007*) commented that these characteristics present serious questions regarding the existing standards and whether current procedures and approaches allow for repeatability of results.

2.4.10.4 Impact of Cross Slope on Retroreflectivity Measurements

The cross slope of a roadway can impact the retroreflectivity readings of a pavement marking. Carlson et al. (*2007*) determined that a 2% cross slope is associated with a 20% increase in retroreflectivity, for 4% cross slopes the retroreflectivity increases by 50% or more.

Cross slope criteria are not included in all the retroreflectivity-related ASTM standards. Carlson et al. (*2007*) recommends the specification of a standard cross slope for measuring retroreflectivity on test decks and recording of cross slope values along with retroreflectivity measurements during in-service performance evaluations.

2.4.10.5 The Impact of Application Thickness on Retroreflectivity

The thickness of thermoplastic pavement markings on surfaces that were recently sealcoated can play a major role in retroreflective performance (Gates and Hawkins 2002a). However, the measurement methodology can greatly impact the accuracy of readings. Gates and Hawkins (*2002b*) evaluated two methods used by the TxDOT to measure the thickness of application for sprayed alkyd thermoplastic pavement markings. On-site thicknesses varied between 60 and 100 mils. They found that the use of a needlepoint micrometer was more accurate than using a standard laboratory caliper. Note that their evaluation considered samples on asphalt and concrete and from the edge line, lane line, and centerline for both white and yellow markings. They also recommend that at least three measurements be acquired diagonally across the sample (with reference to the direction of application) and ideally be located between beads to accurately measure the thickness of the binder material. In the next section, the report covers the analysis of degradation of pavement marking material and retroreflectivity.

2.5 EVALUATION OF NTPEP TEST DECK RESULTS

Until the publication of a study by Wang (*2010*) no reports were available to assess differences in observations at NTPEP test decks across states and installation dates for similar materials. The purpose of this section is to provide a brief background to the study and present findings that are relevant to the ODOT research project.

Wang (*2010*) analyzed NTPEP test deck results for durable pavement markings. The following datasets were analyzed: Pennsylvania (2000, 2002, 2005, 2008); Wisconsin (2004, 2007); Utah (2001, 2005); and Mississippi (2002, 2004, 2006).

Wang reported the following traffic volumes (ADT) for each of the test decks:

- Pennsylvania: 10,000
- Wisconsin: 5,200 – 5,500
- Utah: >5,000
- Mississippi: 20,000.

The Mississippi AADT is consistent with the traffic volumes on the current ODOT test deck.

Wang (*2010*) used minimum retroreflectivity levels to assess service life: 150 mcd/m^2/lux for white and 100 mcd/m^2/lux for yellow markings. The assessment distinguishes between "skip" and "wheel" locations. Measurements are taken on the left wheel track area (referred to as the "wheel" location) to represent the accelerated wear and nine inches from the skip line area (centerline) (referred to from here on as "skip" locations). Wang's research offers findings that are relevant to the ODOT research project in terms of differences across pavement surface, durability, retroreflectivity degradation, service life duration, irregular peaks in retroreflectivity readings across time, effects of snowplowing, retroreflectivity differences across pavement marking colors, and impact of weather on field observations during the evaluation process. The following subsections present discussions on each of these items.

2.5.1.1 The Effect of Pavement Surface on Durability, Color and Retroreflectivity

Wang *(2010*) did not observe any obvious differences between performance on asphalt and concrete surfaces.

2.5.1.2 Durability of Pavement Markings

Most of the deterioration of the pavement markings occurred in the first year and was more pronounced for wheel retroreflectivity compared to skip retroreflectivity. Most of the pavement markings did not reach levels below a durability rating of 5 over a three-year testing period.

2.5.2 Retroreflectivity Degradation

Most pavement markings reached the end of service life in less than two years when assessed based on wheel retroreflectivity. The opposite was true for skip retroreflectivity; in most cases the NTPEP evaluation was completed before pavement markings reached the end of service life.

2.5.3 Irregular Peaks in Retroreflectivity Readings Across Time

Readings showed irregular peaks and troughs for retroreflectivity curves during the same observation interval which may be indicative of dirt accumulation or "calibration variations of retroreflectometers". Wang offered three possible explanations for these irregular values:

- retroreflectivity measurements were not taken at exactly the same location on a particular line;
- pavement marking wearing is exposing beads that were initially embedded more than 50%; or
- installations used higher than necessary bead volumes that resulted in a "shadowing effect" that is characterized by lower initial material retroreflectivity.

2.5.4 Effects of Snowplowing

Snowplowing appeared to rapidly reduce retroreflectivity in states using snowplows and was more pronounced in the first winter after installation.

2.5.5 Retroreflectivity and Durability Differences across Pavement Marking Colors

In terms of retroreflectivity white markings initially have higher retroreflectivity values than yellow markings. Retroreflectivity deterioration rates were similar when comparing yellow and white markings of the same material but deterioration trends differed substantially between different materials. Durability appeared to be consistent across white and yellow pavement markings.

2.5.6 Impact of Weather on Test Deck Field Evaluations

Field evaluations were less frequent in some regions because of weather constraints.

2.5.7 Initial Retroreflectivity and Long Term Retroreflectivity Performance

High initial retroreflectivity did not appear to be consistently indicative of retroreflectivity across time.

2.5.8 Consistency of Observations Between Test Decks

There was variability between observations at the different test decks. The variability in retroreflectivity was the lowest for wheel locations compared to skip locations. The retroreflectivity at wheel locations was relatively similar across the test decks. The observation is interesting because traffic volumes differed substantially among some of the test decks.

2.5.9 Color Specifications for Pavement Markings

Wang (*2010*) noted particular concerns regarding the white color specification, highlighting the fact that the current process does not sufficiently "identify materials with poor color performance."

2.6 ANALYSIS OF DEGRADATION OF PAVEMENT MARKING MATERIAL AND RETROREFLECTIVITY

This section discusses various efforts related to the analysis of the degradation of pavement materials and the associated retroreflectivity. Ideally an agency would be able to develop degradation curves with data from a pavement marking test deck to estimate expected failure and subsequently drive decisions regarding material selection and qualification. This section summarizes various efforts and the difficulty associated with obtaining degradation curves.

Ordinary least-square techniques are most commonly used to estimate degradation of retroreflectivity of pavement markings over time (*Sathyanarayanan, Shankar and Donnell 2008*). Other methods found in the literature include the use of the following:

- Weibull analysis of single-site cross-sectional data by Sathyanarayanan, Shankar and Donnell (*2008*);
- Time series autoregressive moving average methods to estimate lag effects across time (*Zhang and Wu 2005*); and
- Graphical or trend analysis of degradation (*Lagergren, Bertsch and Fernald 2005, Long, Abu-Lebdeh and Ahmed 2006*).

Kopf (*2004*) reported that, based on a study of pavement markings in the State of Washington, the development of degradation curves for the retroreflectivity of pavement markings is difficult if not impossible, even with a considerable amount of data.

Of all the approaches, Weibull analysis appears to offer particular advantages in the analysis of pavement marking retroreflectivity degradation. It can be used to determine the probability of reaching a particular retroreflectivity level during the degradation process; and the instantaneous potential to reach a particular retroreflectivity level at a particular time given that it has not reached the level previously (*Sathyanarayanan, Shankar, and Donnell 2008*).

2.7 OTHER EFFORTS TO EVALUATE THE CONDITION OF PAVEMENT MARKINGS

In an asset management survey, Markow (2008) determined that 85% of the 39 responding states assess pavement marking conditions annually. The states, however, use visual inspections to determine pavement marking condition. He determined that adequate specifications and control of quality at the time of installation are necessary for good pavement marking performance.

This section summarizes the results of a number of interviews with states that use snowplows for snow and ice removal and allow studded tires. The interviews focused on efforts to evaluate the condition of durable pavement markings, specifically as the condition relates to wet weather retroreflectivity. Washington State Department of Transportation (WSDOT), Utah Department of Transportation (UDOT), and Pennsylvania Department of Transportation (PennDOT) responded to the request for interviews. Summaries of the interviews appear in Appendix D. The interviews focused on durable longitudinal pavement marking material practices.

2.7.1 Materials Used

Table 2.11 summarizes the types of high performance pavement markings or durable pavement markings that are used by PennDOT, UDOT, and WSDOT.

Table 2.9: Summary of Materials Used for Longitudinal Lines by PennDOT, UDOT, and WSDOT (1/2010)

STATE DEPARTMENT OF TRANSPORTATION	NEW CONSTRUCTION	REMARKING OF EXISTING MARKINGS
PennDOT	• Epoxy • Hot Thermoplastic • Cold Plastic • Pre-formed Thermoplastic • MMA • Polyurea • Polyester • Wet-Reflective Tape.	Typically replace in-kind, as long as that product is meeting expectations and is still available.
UDOT	• Tape rolled in on asphalt (grooved in on concrete) • Epoxy (ungrooved on concrete, warranty contract) on I-15 in Salt Lake Valley	High build waterborne paints is used for maintenance.
WSDOT	• Profiled MMA as a lane line on Interstates and other divided highways in western Washington. • MMA and thermoplastic for transverse and symbol markings. • Grooved 3M tape for some Interstate lane lines in Eastern Washington.	All remarking of long line markings in done in standard (15 mil) waterborne paint. WSDOT has plastic crews for transverse and symbol markings in the three western Washington regions.

2.7.2 Guidelines for the Use of Particular Pavement Marking Materials

PennDOT, UDOT and WSDOT have guidelines for appropriate use of particular pavement marking materials. PennDOT published its guidelines for the appropriate use of particular marking materials in the PennDOT *Traffic Engineering Manual* (Publication 46, Section 3.2.1). WSDOT's Design Manual 1030 contains minimal guidelines for pavement marking material types.

2.7.3 Pavement Marking Material Use

PennDOT includes documentation for the appropriate use of particular pavement marking materials in its Traffic Engineering Manual. For example, the document lists the various materials that are used (along with references to the specific specifications for each) and provides general comments for each of the materials. The Manual also includes recommendations for restriping, recognizing that compatibility issues exists between existing pavement markings and materials used for restriping.

2.7.4 Test Decks

PennDOT and UDOT are currently managing NTPEP test decks.

WSDOT partnered with ODOT in the past but now uses NTPEP and results from other state test decks to approve new materials. WSDOT also, on occasion, conducts one-time tests such as the I-90 Pavement Marking Material Test in 2004 to 2008. WSDOT has published reports on the performance of the I-90 test deck. The I-90 WSDOT test deck tested five different pavement marking materials on a mountain pass in the Cascades. The project team reported that traveling distances limited the ability of the team to take regular measurements and measurements at nighttime. Adverse weather conditions, such as snow, coupled with limited visibility prohibited the team from acquiring measurements other than during dry daytime conditions.

The test decks are generally three-year test decks but UDOT and WSDOT indicated that they will continue testing materials depending on the individual marking performance, i.e. if the material did not fail by the end of three years, observations continue until failure is observed.

Inspection intervals reported by the agencies varied widely. PennDOT reported that the test deck is monitored by the Materials and Testing Lab at installation and then every two months except during the winter maintenance season (November through March). WSDOT monitored the one-time test deck on I-90 during mid-December, mid-February and April of the first winter; during the second year monitoring visits occurred in September and April; followed by a one-time visit in April during years three through six.

Retroreflectivity measurements are taken at UDOT test decks in the spring (after salt and dirt were removed by rain) and in the fall (before the first snowfall). A decaying exponential curve fitting is used to predict failure at 100 mcd/m^2/lux.

2.7.5 Conditional Approval of Marking Materials

PennDOT has an experimental process for conditional approval of marking materials but it is not currently used. Maintenance staff at UDOT use a subjective rating for conditional approval and WSDOT does not currently have systems in place to provide conditional approval of marking materials.

2.7.6 Use of NTPEP for Material Approval Process

PennDOT only uses data from the Pennsylvania NTPEP test deck for their approval process. UDOT uses NTPEP data as part of their approval process but relies mostly on their own field test decks. WSDOT uses data from NTPEP and test decks from other states to approve materials for use on state highways.

2.7.7 In-Service Evaluation Processes

In-service evaluation processes refers to any procedures carried out at installation of materials as part of standard construction projects and monitoring of these installations over time. In-service evaluation processes varies widely across Pennsylvania, Utah, and Washington.

2.7.7.1 Initial Installation Evaluation at Construction Projects

PennDOT construction inspection crews monitor the amount of beads and paint used during installation; carry out wet-film thickness tests; and collect field samples that are tested in the lab. PennDOT requires contractors to provide Certification of Materials for each project. PennDOT also initiated a program whereby each district identifies six check point areas from which to collect retroreflectivity measurements every two months after application. The actual expected data collection frequency is expected to vary among materials and the ability of the particular district to collect the measurements.

Lab tests are only performed on waterborne binders for UDOT projects. WSDOT does not take samples at installation and only carries out minimal testing on most projects.

2.7.7.2 Monitoring of Pavement Marking Conditions After Installation

None of the states interviewed has an in-service performance evaluation program to quantitatively monitor installations on the state highways on a continuous basis. PennDOT uses a subjective rating system. As part of an annual review of pavement marking material performance, WSDOT measures retroreflectivity of a non-stratified sample of 1,800 sites statewide during the daytime as part of the Maintenance Accountability Process.

2.7.8 Snow Removal Processes

PennDOT and UDOT have polices requiring that the roads be kept clear regardless of the impact on pavement marking materials. PennDOT avoids the use of larger beads because of this policy. To remove snow from lower elevation state highways, WSDOT has begun to use deicer to

prevent snow buildup and has reduced the use of snowplows. WSDOT uses deicer and snowplowing on mountain passes for snow removal.

2.7.9 Night-time RetroreflectivityMonitoring

PennDOT performs retroreflectivity measurements during installation and then carries out random measurements of district-installed lines. UDOT does not carry out any night-time retroreflectivity measurements after installation. WSDOT regional striping crews conduct some night-time retroreflectivity observations to plan for the upcoming striping season.

2.7.10 Wet-Weather Retroreflectivity Monitoring

UDOT is currently evaluating the use of a 50% addition to wet weather retroreflective beading into waterborne paint under grooved conditions as a possible wet weather retroreflective application for striping. Even though the evaluation team is using the relevant ASTM standards in measuring the wet weather retroreflectivity, UDOT commented that the retroreflectivity values do not appear to reflect the improved visibility conditions under wet nighttime conditions. The evaluation team is also finding large variations in the retroreflectivity measurements for lines that were installed at the same time and that are experiencing the same traffic conditions.

2.7.11 Alternative Methods to Improve Nighttime Wet-Weather Visibility of Longitudinal Markings

PennDOT uses snowplowable RPMs (SRPMs) on all interstates while their district offices maintain SRPMs in high-volume locations. PennDOT spends $3 to $4 million annually on SRPMs.

UDOT does not use RPMs and is evaluating alternative paint-bead configurations to serve as wet-weather retroreflective application for striping.

WSDOT uses raised and recessed reflective pavement markers on state highways.

2.7.12 Efforts to Determine Life Expectancy of Pavement Markings

UDOT evaluated and quantified the relationship between the life expectancy of pavement markings and AADT (*Martin, et al. 1996*). The procedure used AADT and age of the markings to predict retroreflectivity levels and estimate service life. Subsequently the studies by UDOT also used methods that include a visual rating of the marking condition and retroreflectivity measurements.

2.8 OTHER PUBLISHED STATE-LEVEL ACTIVITIES

The TxDOT has invested substantial funds into pavement marking retroreflectivity and the topic of measurement of wet weather retroreflectivity. As discussed earlier, Carlson et al. (*2007*) recommended that TxDOT use RRPMs with standard thermoplastic pavement markings as the most cost-effective alternative for wet-nighttime conditions.

Shahata, et al. (*2008*) developed a set of conditional rating models to assess the effectiveness of pavement marking applications for the Province of Quebec. Quebec depends on visual inspection and does not measure retroreflectivity. The study was limited to alkyd and epoxy pavement marking materials. The models utilized a 5-category scale (ranging from 'excellent' to 'critical'). The researchers used multiple regression analysis methods to estimate the pavement marking condition combined with the use of some of the measures included in Table 2.5.

Sathyanarayanan, Shankar and Donnell (*2008*) evaluated the results from a 2002 Pennsylvania waterborne paint test deck using a Weibull analysis. The purpose of their research was to develop life-cycle models for pavement marking retroreflectivity. This analysis approach offers advantages in terms of data-driven pavement marking management systems. The results of this analysis allow for an estimation of Weibull scale and shape parameters that can be used to support maintenance related decisions. Typical results would include an estimated time for replacement of pavement markings, comparisons among different material types, and a probability interval for a particular pavement marking material maintaining a particular retroreflectivity level above a certain mcd/m^2/lux level. The study only evaluated one test site and, to improve parameter estimates, recommended multi-site analysis to allow for the temporal and spatial differences. The approach can also be used to compare results from test decks and in-service performance. The researchers also suggested that semiparametric and nonparametric duration models be considered for estimating pavement marking retroreflectivity reduction.

The PennDOT has hosted several NTPEP test decks and is continually evaluating pavement marking materials on their test deck using ASTM International standards.

The Iowa DOT has spent a significant amount of effort in funding research related to pavement marking management systems.

2.9 RAISED REFLECTIVE PAVEMENT MARKERS

Agencies often use raised reflective pavement markers (RRPMs) in combination with other pavement markings. Although this study focuses on durable pavement markings, it is worth mentioning that the presence of RRPMs affects the visibility of durable pavement markings and that the use of these markers has been recommended as a wet-weather nighttime delineation treatment (*Carlson et al. 2007*). This recommendation is consistent with the recommended minimum R_L levels suggested by Debaillon, et al. (*2008*) (Section 2.4.7) that provide for lower minimum R_L levels in the presence of RRPMs.

Information provided by RRPMs is intermittent and should provide short-range and long-range direction to the driver. In terms of short-range information to support tasks such as passing and lane changes, Zwahlen and Schnell (*1997*) recommended a 80-ft (24.38 m) detection distance (1 second preview time for a driver in a vehicle travelling 55-mph). This is consistent with recommendations by Debaillon et al. (*2008*) and Zwahlen and Park (*1995*). To meet the long-range nighttime information needs of the driver, Zwahlen and Schnell (*1997*) proposed that at least three RRPMs that are in good condition be visible at all times.

Debaillon et al. (*2007*) reported average detection distances for RRPMs in good condition of more than 550-ft (167.64 m): approximately 200-ft (60.96 m) more than any of the other

pavement markings. Their findings were consistent with recommendations by Zwahlen and Schnell (*1997*) that suggested a reduction in preview time by 1.65 seconds to 2.0 seconds when used on fully marked two-lane highways with RRPMs. When at least three RRPMs in good condition are visible, Debaillon et al. (*2008*) determined that the minimum R_L can be reduced with the addition of RRPMs to 31 to 48 mcd/m^2/lux for centerline-only two-lane rural highways and even further to 18 to 34 mcd/m^2/lux for highways with center and edge lines.

According to Carlson et al. (*2007*) RRPMs are highly cost effective, providing a "visiblity per dollar spent… that is seven times greater in dry conditions and eight times greater in wet conditions than any of the other markings." They recommended that the TxDOT use RRPMs as wet-night delineation treatment instead of specifying particular pavement marking materials that would meet the current wet-weather retroreflectivity ASTM standards. Fontaine and Gillespie (*2009*) confirmed this in a conservative estimate of a benefit:cost ratio of 80:1 for snowplowable raised pavement markings.

Fontaine and Gillespie (*2009*) recommended to the Virginia Department of Transportation (VDOT) that RRPMs be used on all two-lane rural highways with an AADT greater than 15,000 vehicles per day, on all limited access freeways, and on all facilities with posted speed limits 60-mph and more. They also recommended a maintenance schedule for RRPMs installed on these facilities.

2.10 ONGOING AND RECENTLY COMPLETED FEDERAL AND STATE RESEARCH IN THIS AREA

Federal and state government are funding several pavement marking related research projects. This section summarizes projects with scheduled completion dates of 2009 and later. For the purpose of the discussion, the areas of research are categorized as follows: those related to (1) the relationship between retroreflectivity of pavement markings and safety; (2) durability of wet-night pavement markings; (3) surface treatment strategies to improve the durability of inlaid pavement markings; (4) pavement marking management systems; (5) glass beads; (6) statistical methods to predict service life of longitudinal pavement markings; (7)pavement marking warranty specifications; and (8) monitoring pavement marking performance. Expected completion dates listed represent dates reported on the Transportation Research Board's Research in Progress (RiP) website (http://rip.trb.org/) or DOT research web pages.

2.10.1 The Relationship Between Pavement Markings and Safety

Smadi, Hallmark, and Hawkins from the Institute for Transportation at Iowa State University in Ames, Iowa recently completed an evaluation of the safety effect of pavement markings. The researchers are specifically considering the effect of varying levels of pavement marking retroreflectivity on crashes. The research was funded by the Iowa Highway Research Board at the Iowa Department of Transportation. The study did not find a correlation between poor retroreflectivity and higher crash probability across the state network. The researchers did detect a weak relationship between sites with a retroreflectivity of 200 mcd/m²/lx or lower and higher crash probability.

2.10.2 Durability of Wet-Night Pavement Markings

Virginia Polytechnic Institute and State University, Blacksburg and the Virginia Tech Transportation Institute are currently assessing the durability of wet-night visible pavement markings for the Virginia Transportation Research Council. As part of the project, researchers will monitor retroreflectivity of six different pavement marking materials every three months over an 18-month period. In addition, the researchers will monitor degradation as a factor of traffic volume, snow removal activities, and visibility needs of drivers in natural rain conditions. Reported expected completion date: May 2011.

2.10.3 Surface Preparation for Inlaid Durable Pavement Markings

Wehbe, Mahgoub, and Jones from South Dakota University are evaluating strategies to minimize the impact of surface treatments, such as chip seals, on the durability of inlaid pavement markings. The work is being done for the Federal Highway Administration and is expected to be completed in December 2011.

2.10.4 Pavement Marking Management Systems

Iowa State University is currently developing an Iowa Pavement Marking Management System (PMMS) as part of the University Transportation Center research efforts.

In Canada, Dr. Tarek Zayed from the Department of Building, Civil and Environmental Engineering, Concordia University, is conducting research in the area of Web-based Pavement Marking Management Systems (WPMMS). The research is funded by Infrastructure Canada. The process includes consideration of minimum retroreflectivity levels.

Williams and Hummer from the Department of Civil Engineering at North Carolina State University recently completed efforts related to pavement marking degradation and modeling to estimate expected service life for thermoplastics and paint pavement markings in North Carolina. The project was funded by North Carolina Department of Transportation.

2.10.5 Glass Beads

Smadi from Iowa State University is conducting research for the National Cooperative Highway Research Program to develop a recommended test for a typical state DOT materials testing laboratory to estimate initial retroreflectivity of glass beads. This project was initiated because glass beads with the same gradation, roundness, and application rate can have retroreflectivity differences among batches of 200 mcd/lx/sq m. Other research done in Iowa concluded that an increase of initial retroreflectivity from 100 to 200 mcd/lx/m^2 can increase service life by a year.

2.10.6 Statistical Models to Estimate Service Life

Pennsylvania State University is currently doing research for PennDOT to develop statistical models to predict service life of longitudinal pavement markings.

2.10.7 Pavement Marking Warranty Specifications

Markow is currently developing a synthesis of pavement marking warranty specifications for the National Cooperative Highway Research Program.

2.10.8 Monitoring Pavement Marking Performance

Pigman from the Kentucky Transportation Center at the University of Kentucky is evaluating pavement marking performance for Kentucky DOT and developing specific recommendations for the application and installation of the markings.

2.11 CONCLUSION

The literature review provided insight into the testing, evaluation, and monitoring of durable pavement markings. The topic is, however, complex and it is hoped that ongoing and new research will further knowledge in the field.

Findings most relevant to ODOT and the ODOT test deck can be summarized as follows:

- Data collected at the NTPEP test decks are available to all AASHTO member states. Some states are using NTPEP results as part of their pavement marking selection process. Test decks are alternated annually between states using snowplows and those that don't. ODOT can benefit from reviewing test deck results from states using snowplows and studded tires. One such a state is Utah which has hosted multiple test decks.
- Research results did not provide insight as to the minimum and optimal length of a test deck but rather, current practice indicate that some materials warrant monitoring beyond the NTPEP standard of three years. Periods shorter than two years are appropriate for other types of maerials.
- Measuring wet-weather and night-time wet-weather retroreflectivity is difficult in practice because of exposure of staff to traffic, adverse weather conditions, and concerns regarding repeatability. These measurements are rarely carried out on a regular basis across a roadway network.
- Efforts to accurately predict time to failure of pavement marking retroreflectivity using data from test decks have been unsuccessful thus far.
- The differences between typical locations of use and those of test deck specifications may result in material selection that may not be optimal for environments of high wear.

3.0 CURRENT ODOT PAVEMENT MARKING TESTING

3.1 ODOT ORGANIZATION

3.1.1 Introduction

Effective pavement markings are critical for ODOT as they help provide positive guidance to the driver, enhance safety, and provide savings in cost and time by enabling proper material selection and application. In addition, the use of pavement markings varies in application and need, and therefore different offices and personnel share the responsibility for durable pavement marking procedures, standards, specifications and selection process as discussed in the remainder of this section. The offices with the primary roles and responsibilities include: the Office of Statewide Maintenance, the Construction Section, the Traffic-Roadway Section, and the ODOT Regions. Also discussed in this section is the role of the Statewide Stripping Committee.

3.1.2 Office of Statewide Maintenance

The Field Operations Specialist from the Office of Statewide Maintenance is responsible for managing the Pavement Marking Test Deck and for oversight of all Region Striping Crew maintenance practices. The test deck process is detailed in the document, Permanent Pavement Markings for Use on Oregon Department of Transportation (ODOT) Highways which appears as Appendix E.

The Field Operations Specialist also holds the original construction warranties for reference purposes if a particular region has after-the-fact issues with the pavement markings on a particular construction project. A warranty is required for each construction project with durable or high performance pavement markings. The warranty statement clearly states the warranty period for the particular pavement marking application. The manufacturer is responsible for repairing or replacing the particular pavement marking application (at no additional cost to ODOT) if any of the markings "drop below the required minimum retroreflectivity, show insufficient color stability, or fail" within six months of ODOT's request for repair or replacement (statement from the ODOT Warranty Statement for Durable Longitudinal Pavement Markings, dated 02-25-09).

3.1.3 Construction Section

The Product Evaluation Coordinator from the Construction Section is the point of contact for the Qualified Products List (QPL) for a range of products including pavement marking materials. He places pavement marking materials on the QPL that were on the test deck and found to be satisfactory and, at the direction of the Field Operations Specialist, transfers materials from conditionally approved status to approved status.

ODOT assigns an inspector to every construction project and a manufacturer's representative is on site full-time during the pavement marking installation (for durable and high performance pavement markings). It is standard practice that the manufacturer's representative takes retroreflectivity measurements and monitors the installation for issues that pertain to warranting the material. These measurements are reviewed by ODOT for acceptance of the particular striping application. The inspector is responsible for quality control on-site during striping installation and reports to the Project Manager assigned to the particular construction project.

3.1.4 Traffic-Roadway Section

The ODOT Traffic Devices Engineer from the Traffic-Roadway Section is responsible for statewide pavement marking standards, such as the standard drawings, standard details and specifications as they relate to pavement markings. The Traffic Devices Engineer is also the point of contact for operational requirements related to pavement markings (such as the Manual on Uniform Traffic Control Devices (MUTCD)), training related to pavement markings and pavement marking related manuals. The Traffic Devices Engineer maintains two pavement marking related manuals: the *Striping Design Guidelines* (which includes striping computer-aided design (CAD) standards for contract plans), and the *Traffic Line Manual*. A third manual is currently under development: an inspector training manual for pavement marking installation. The Traffic Devices Engineer has served on the Test Deck Review Panel.

3.1.5 ODOT Regions

Striping practices differ among ODOT's five regions for a number of reasons such as: varying levels of urbanization, differences in climatic conditions, and different traffic volume levels. The Region Striping Managers develop annual work plans for restriping and are responsible for maintaining acceptable retroreflectivity and line presence on the highways within their region. These managers use the work plans and material needs identified by their crew to estimate maintenance related striping expenditures.

Vendors often contact Striping Managers individually and request an opportunity to apply new materials for in-service review by the region. Materials evaluated in this way are not eligible for inclusion on the QPL until they are placed on the test deck and determined to be qualified.

Within ODOT the replacement of pavement markings is coordinated by the Region Striping Managers who choose marking materials and applications they deem appropriate as provided by the work plan they develop. The pavement markings are either replaced by construction projects, by stand-alone pavement marking projects, or by in-house work. Construction projects use products that are on the QPL or QPL conditional list. Stand-alone pavement marking projects are more flexible and ODOT has the ability to use products on the QPL or try new products. ODOT in-house work uses purchasing contracts for the products on the QPL.

3.1.6 Statewide Striping Committee

The ODOT Statewide Striping Committee (SSC) consists of representatives from each of the ODOT regions and includes their Pavement Striping Manager, a representative from the Office

of Maintenance, a person from the Traffic-Roadway Section, and a Project Manager. The SSC is chaired by an ODOT District Manager. Staff from FHWA, the Research Section, and the Construction Section serve as advisors to the SSC. The purpose of the SSC is defined as follows:

"The Statewide Striping Committee (SSC) provides strategic planning, oversight, specification review/development, and guidance for the ODOT pavement marking program. The SSC's key goals are:

- To develop and execute a strategic plan for pavement marking (including durable products) – plan to be approved by the Maintenance and Operations Leadership Team (MLT).

- To promote statewide consistency through relevant practice, procedures, standards, and specifications.

- To provide technical expertise to insure that the ODOT pavement marking program is implemented in a cost effective and efficient manner."

The adopted charter for the committee is included as Appendix F.

The SSC provides an opportunity for those involved in decisions regarding the planning, design and installation of pavement markings to coordinate efforts, identify challenges and work together towards a common goal. The SSC has not been directly involved in the pavement marking test deck.

3.1.7 Other General Comments

This section provides additional background about the durable pavement marking procedures, standards, specifications and selection process within ODOT that are relevant to this research project.

A number of activities related to the ODOT procedures, standards, specifications and selection process for durable pavement markings are currently underway. These include:

- ODOT is considering modifying the requirement of a warranty from the manufacturer to a warranty from the contractor.

When pavement marking striping activities occur as part of a construction project, ODOT's inspector typically does not take measurements to assess retroreflectivity performance or to validate the assessment performed by the manufacturer's representative. To that end, the Traffic Devices Engineer is currently developing additional testing protocols for striping acceptance and inspector training in striping quality control. ODOT expects that this will eliminate the need for a full-time on-site manufacturer's representative and support improved risk management for ODOT.

3.2 ODOT PAVEMENT MARKING MATERIALS TESTING

3.2.1 Background

ODOT requires that pavement marking materials used on construction projects be selected from materials on the Qualified Products List (QPL). To be included on the QPL, pavement marking materials must be tested using the ODOT Pavement Marking Test Deck. A NTPEP test deck was held in Oregon in 1995 and ODOT has held its own test decks in 1999, 2001, 2003, 2004, 2005, 2006, and 2007. ASTM testing standards have been used for guidance.

Oregon hosted an NTPEP test deck in 1995 but has not participated in subsequent NTPEP test decks held in other states. It is felt that the use of studded tires in Oregon places greater demands on pavement markings and therefore make NTPEP test deck results less representative of Oregon conditions.

Materials are evaluated initially and periodically by a review panel composed of at least three ODOT staff members. In this discussion, the panel is referred to as the Test Deck Review Panel.

The next section describes the test deck procedures that were used for the most recent test deck conducted from 2007-2009. Section 3.3.3 provides a summary of changes that have either been made to the test deck procedures or are being considered for implementation for the next test deck. Section 3.3.4, provides the observations of ODOT's process made by the research team.

Other materials, such as raised pavement markers, are also tested for inclusion on the QPL. The discussion in this section is limited to testing for longitudinal durable pavement marking materials.

3.2.2 Current Test Deck Procedures

The current test deck is located on OR 22, east of Salem, at approximately milepost 6.0. OR 22 is a multi-lane highway with approximately 22,000 ADT, The test deck includes both asphalt and portland cement concrete. Manufacturers apply four transverse lines per submitted sample, two on concrete and two on asphalt pavement surfaces. Manufacturers also submit an additional sample to ODOT that is placed in the QPL file.

The ODOT Test Deck Review Panel evaluates and monitors the markings initially and over time to assess durability and appearance and makes a determination of suitability for inclusion on the QPL. The 2007 Test Deck Review Panel consisted of representatives from the Office of Maintenance, the Traffic-Roadway Section, and the Research Section.

The current test deck procedures consist of six steps.

- *Step 1: Solicitation of samples:* The Field Operations Specialist distributes a general solicitation for submittal of pavement marking material samples for inclusion on the test deck and consideration for inclusion on the QPL. Interested parties submit the necessary paperwork as specified in the "Solicitation for Samples" (Appendix G) and pay a fee per sample ($900 in 2007).

- *Step 2. Test deck site preparation:* The Field Operations Specialist makes the necessary arrangements for application of samples to the test deck on a particular day. This includes arranging for traffic accommodation.

- *Step 3. Application of pavement markings to the test deck:* On the chosen date, manufacturers apply the various samples to the test deck. Manufacturers apply four transverse lines with material from each sample: two on asphalt and two on concrete pavement surfaces. The Test Deck Review Panel numbers each of the transverse lines and records related sample information. The panel members measure the thickness of applications but do not reject any sample where the measured thickness exceeds the expected thickness of application on construction projects. Thickness is measured using cutout gauges for 90, 120, and 160 mil (1 mil = 0.001 inch = 0.0254 mm). The panel members measure retroreflectivity parallel to the transverse line between wheel track locations and record these measurements.

- *Step 4. Periodic site visits*: The Test Deck Review Panel carries out periodic site visits to evaluate durability, appearance and retroreflectivity of the markings. The panel follows the ASTM D713-90 standard in the assessment process. Each panel member records assessment results for each line. The panel does not monitor wet weather retroreflectivity for daytime or nighttime conditions at the test deck.

- *Step 5. Evaluation of test results*: The panel assesses results from the periodic site visits and makes recommendations to the Product Evaluation Coordinator regarding QPL determination. Each tested material is given approval, conditional approval, or is rejected.

- *Step 6: Consideration of pavement marking materials for Conditional and QPL status:* Pavement marking materials on the conditional approved list are periodically evaluated for in-service performance and given approved or rejected QPL status as deemed appropriate.

The last new application of pavement markings to the ODOT test deck took place during the summer of 2007. At the time of the test, the facility was approximately 10-years old. For the 2007 test deck, the Test Deck Review Panel evaluated the samples on the day of application and three additional times for durability, appearance and retroreflectivity. The panel reports that weather conditions and time constraints were the main obstacles to regular and more frequent monitoring visits. Table 3.1 summarizes the results.

Table 3.1: 2007 ODOT Pavement Marking Test Deck Results

Sample #	Type	Color	Appearance	Durability	Retroreflectivity (mcd/m2/lx)	Thickness(mils)			QPL Action
			Asphalt/PC/Ave	Asphalt/PC/Ave	Asphalt/PC/Ave	Asphalt	PC	Avg	
1	Durable	W	6.0/1.4/3.7	6.0/1.8/3.9	187.1/186.9/187.0	116.67	95.00	105.83	Rejected
2	Durable	W	8.0/3.8/5.9	6.7/4.0/5.3	156.7/167.4/162.1	186.67	126.67	156.67	Rejected
3	Durable	Y	testing terminated						Rejected
4	Durable	W	8.2/4.8/6.5	6.7/5.7/6.2	166.1/171.1/168.6	146.67	126.67	136.67	Qualified
5	Durable	W	testing terminated						Rejected
6	Durable	W	7.5/5.9/6.7	6.6/7.8/7.2	149.9/173.9/161.9	126.67	148.33	137.50	Qualified
7	Tape	W	3.1/2.9/3.0	2.7/4.2/3.5	142.6/165.1/153.9	90.00	90.00	90.00	Conditional
8	Tape	Y	4.1/4.4/4.3	4.5/5.8/5.2	114.3/119.9/117.1	90.00	90.00	90.00	Conditional
9	Thermo	Y	testing terminated						Rejected
10	Thermo	W	testing terminated						Rejected
11	Durable	Y	8.0/5.0/6.5	7.3/6.5/6.9	135.3/12.6/130.5	133.33	105.00	119.17	Qualified
12	Durable	Y	5.2/1.6/3.4	4.9/1.3/3.1	138.4/150.0/144.2	120.00	90.00	105.00	Rejected
13	Durable	Y	2.5/4.8/3.6	2.9/6.2/4.5	132.0/131.4/131.7	140.00	133.33	136.67	Rejected
14	Durable	Y	6.2/4.0/5.1	5.8/5.2/5.5	124.2/136.2/130.2	126.67	100.00	113.33	Qualified
15	Durable	W	testing terminated						Rejected
16	Durable	Y	testing terminated						Rejected

Note: Products marked "testing terminated" failed prior to the end of the evaluation. Appearance, Durability, Retroreflectivity from May 21, 2009 site evaluation. Thickness determined on date of installation, August 23, 2007.

3.2.3 Changes to Test Deck Procedures

Following completion of the 2007 test deck evaluation, the Test Deck Review Panel met to review the testing procedures and QPL acceptance process. Among the issues identified for consideration were the following:

- Lack of documentation of results or publication of report.
- Inconsistent timeframes for making QPL status decisions on products placed on the test deck
- Long timeframe (two years) for the test deck.
- Lack of clear procedure and expectations (for ODOT staff and manufacturers)
- Inconsistent results from reviewers due to lack of training

The panel met with others involved in the pavement marking testing and approval process and identified issues to be addressed prior to implementation of the next test deck. These issues are described in the following sections.

3.2.3.1 General

- Review the NTPEP and determine if and how Oregon can utilize the results in the QPL acceptance process
- Ensure test deck and QPL acceptance procedures are consistent with other ODOT manuals (i.e. QPL product review guidelines, Nonfield-Tested Materials Acceptance Guide (NTMAG), specifications, etc.)

3.2.3.2 Pavement Marking Materials Placed on the Test Deck

- Document a clear process and timelines for a product seeking QPL approval. Also the reverse – how a product stays on the QPL and what constitutes rejection of an accepted QPL product.
- Review independent lab testing requirements and determine if they are still adequate.
- Develop tighter controls/process for test deck installation.
- Determine the proper timeframe needed to make good decisions on different types of products.
- Establish durable and high-performance control samples possibly using the products listed on the state maintenance contract.
- Establish a refined evaluation process for determining pass/fail status, possibly based on a performance index and comparing test results to a control sample.
- Establish a component approval package – i.e. listing binder and bead specification on the QPL.

- Document the products tested, procedures followed, and results in a report.

3.2.3.3 Test Deck Review Panel

- Establish a group of approximately 10 people who will commit to participating test deck evaluations with three to five participating in any one evaluation.
- Develop training for the staff that will be evaluating the test deck.

3.2.3.4 Pavement Marking Materials Not Placed on the Test Deck

- Develop a process for evaluating in-service projects (region maintenance and construction projects) that ties into the QPL approval process.
- Develop a process for use of conditionally approved products on projects (small quantities, low risk areas, etc).

3.2.4 Observations

In terms of the test deck, the following practices may also affect existing and future procedures, standards, specifications and selection processes for durable pavement markings within ODOT:

- Within the ODOT QPL process, ODOT only approves the pavement marking binder material for waterborne paint to the QPL list. Beading types and sizes are not included as part of the approval process.. A contractor can use any type of bead on the QPL with waterborne paint but beading for durable pavement marking material is limited to the beads recommended by the material manufacturer.
- When a manufacturer applied pavement marking materials to the test deck in 2007, thickness measurements were collected but none of the samples were rejected even if the measured thickness far exceeded the thickness of expected field application.
- For thermoplastic pavement markings, thickness measurements are acquired with cutout gauges and to the top of the drop-in beads rather than to the top of the binder with a needlepoint micrometer as suggested by Gates and Hawkins *(2002b).*
- ODOT has not determined whether the studded tire exposure at the test deck (near Salem) is representative of the studded tire vehicle volumes at locations across the state that experience snowfall.
- ODOT has not determined whether the snow removal practices (such as the bit type used by the snowplows) at the test deck are representative of snow removal practices at other locations where durable pavement markings are used.

These observations and the list of possible changes to the pavement marking test deck identified by the Pavement Marking Review Panel and others involved in the test deck process form the basis for the recommendations made in the next chapter.

4.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 SUMMARY

The Oregon Department of Transportation (ODOT) is responsible for over 26,000 line miles of longitudinal pavement markings of which 29% represent durable markings. ODOT requires performance and durability testing of all pavement marking materials before the materials can be applied on construction projects on state highways. ODOT requires warranty statements and certifications for each construction project that installs durable or high performance pavement markings.

Manufacturers wanting their products considered for use on construction projects apply materials on a two-year test deck where the product is evaluated, using ASTM testing procedures, and a determination is made regarding the suitability of the marking material. If it is determined that the material meets minimum criteria, it is included on the Qualified Products List (QPL). The testing and evaluation on ODOT test decks are limited to measuring the thickness of the marking material; assessing dry weather retroreflectivity; and subjective evaluations of appearance and durability. The tests do not include an assessment of wet-weather retroreflectivity. This would be desirable as Oregon has many days with rainy weather conditions. Due to snow and ice conditions and the use of snowplows in mountainous areas, studded tires are allowed for approximately five months each year. These conditions challenge ODOT to identify pavement marking materials that cannot only withstand the additional wear caused by the studded tires but can provide adequate guidance for drivers during wet weather. The initial purpose of the research project was to identify appropriate wet weather testing to add to our test deck procedure.

During the first phase of the research, unexpected findings in the literature review indicated that measurement of retroreflectivity under wet weather conditions is particularly difficult (requiring closely monitored laboratory conditions) and that wet weather retroreflectivity measurements are often inconsistent and not repeatable. Studies recommended the use of raised reflective pavement markers (RRPMs) to supplement pavement markings rather than further development of wet weather pavement marking materials.

The literature review and the review of current ODOT practices also revealed that ODOT pavement testing practices could be improved and that there are opportunities to benefit from the National Transportation Product Evaluation Program (NTPEP) test decks conducted in states with climatic conditions similar to those in Oregon. The objectives were revised to focus on enhancements that could be made to Oregon's pavement marking testing procedures. The research was refocused toward placing ODOT in the best possible position to respond to proposed changes in federal standards.

Most states participate in NTPEP. Oregon, however, does not participate, stating that the use of studded tires would make results of tests in other states irrelevant for application in Oregon. NTPEP testing is conducted following a NTPEP Best Practices Manual that specifies, among other things, the use of test deck mapping and the use of such a map for recording evaluation readings. The Manual also provides guidance on evaluation intervals for installations: an initial evaluation within seven days then approximately every 30 days for the first year and every 120 days for the second year. As wear occurs more rapidly during the second year, more frequent, possibly monthly, evaluation is desirable. The periodic field evaluations include retroreflectivity, wet-night retroreflectivity (if requested by the manufacturer), night color of yellow markings, day color, durability and photo logging.

In April of this year, FHWA published proposed rules for minimum retroreflectivity of longitudinal pavement markings that include minimum retroreflectivity levels that must be maintained on different types of roads and at different posted speeds. The highest level of retroreflectivity that must be maintained for longitudinal markings is 250 mcd/m^2/lux. This is on two lane roads with centerline markings only with a posted speed of 55 mph or greater. If Retroreflective Raised Pavement Markings (RRPMs) are maintained so that at least three are visible from any position along that line during nighttime conditions, then the requirements do not apply.

Because this proposed rule is based on a congressional mandate, it is likely that requirements regarding minimum retroreflectivity and maintenance methods to maintain such retroreflectivity will be adopted later this year or in early 2011. FHWA proposes a phase-in period of four years for the minimum retroreflectivity requirements.

Adoption of the proposed rule will require that all states meet the minimum requirements at all locations or has one or more of the following methodologies (referred to as "MUTCD maintenance methods" in place for assessing pavement marking replacement:

- *Calibrated Visual Nighttime Inspection* by a trained inspector. Pavement markings identified by the inspector to have retroreflectivity below the minimum levels are replaced.
- *Consistent Parameters Visual Nighttime Inspection* by a trained inspector who is at least 60 years old. Pavement markings identified by the inspector to have retroreflectivity below the minimum levels are replaced.
- *Measured Retroreflectivity* in which pavement marking retroreflectivity is measured using a retroreflectometer. Pavement markings with retroreflectivity levels below the minimums are replaced.
- *Service Life Based on Monitored Markings* in which the replacement of markings is based on the monitored performance of similar markings with similar placement characteristics. All pavement markings in a group, area, or corridor are replaced when those in the representative monitored control set are near or at minimum retroreflectivity levels.

- *Blanket Replacement* in which all pavement markings in a group, area, or corridor or of a given type are replaced at specific intervals. The replacement interval is based on when the shortest-life material approaches the minimum retroreflectivity level. Historical retroreflectivity data is used.
- Other methods, based on engineering studies, can be used to determine when markings should be replaced.

ODOT currently does not have a MUTCD maintenance method in place.

When considering the different MUTCD maintenance methods currently referenced in the proposed FHWA rulemaking, an approach that incorporates analysis of retroreflectivity performance with a review of a control group of markings offers a good opportunity for meeting compliance requirements. Previous research indicates that determination of the useful service life and retroreflectivity performance of durable longitudinal pavement markings is a difficult task. Installation conditions, chemical and physical characteristics of the material along with exposure to wear (including exposure to snowplows and studded tires) and physical location can all impact the useful service life and retroreflectivity performance of a particular marking.

4.2 CONCLUSIONS

4.2.1 NTPEP Test Deck

The use of snowplows and studded tires rapidly degrades retroreflectivity and accelerates wear of durable pavement markings. NTPEP alternates test decks between states using snowplows and those that do not. States such as Oregon, Washington, Utah, and Pennsylvania use snowplows and allow studded tires on all or some of their network which results in extensive damage to pavement markings. UDOT and PennDOT participate in the NTPEP test decks and have hosted several test decks over the last few years and WSDOT incorporates consideration of NTPEP test deck results in their product approval process. While Oregon hosted a test deck in 1995 and reviews the reports from other test decks, Oregon has not actively participated in recent NTPEP test decks.

Besides using NTPEP test deck results as part of the product approval process the data are also used by states such as PennDOT and UDOT to estimate the useful service of life. Prior research indicates that useful service of life is best approximated by using the Weibull distribution to determine time to failure of retroreflectivity degradation processes.

ODOT would benefit from participating in the NTPEP test decks and reviewing results from the test decks to use as comparisons with its own test decks, inform maintenance decisions regarding optimal replacement schedules, provide data for estimating useful service of life at no or limited additional expense. With scheduled replacement based on useful service of life ODOT would meet one of the MUTCD maintenance methods that are likely to form part of the anticipated FHWA rule on minimum retroreflectivity requirements. It is also likely that such scheduled replacement would lead to cost savings for ODOT compared to blanket replacement activities that will be required in the absence of institutionalization of one or more of the MUTCD maintenance methods.

4.2.2 ODOT Test Deck Procedures

The ODOT test deck procedures in use for the 2007 test deck warrant review, particularly in light of the fact that:

- ODOT has not included bead size, bead coating and application rates as part of the product specification when a particular sample is included in the QPL. Bead size, bead coating, and application rates are all factors that can substantially impact retroreflective performance of a pavement marking. The current specification states that beads off the QPL or beads recommended by the manufacturer should be used.
- The thickness of samples provided at the test deck was measured and some exceeded the maximum thickness threshold yet none of the submitted samples were rejected based on thickness alone. The thickness of initial application has a substantial impact on useful service life of a pavement marking.
- ODOT uses cut-out gauges for measuring marking thickness and measures to the top of the drop-in beads. Previous research indicates that the use of a needlepoint micrometer to measure to the top of the binder better estimates marking thickness.
- ODOT has not determined whether the studded tire exposure at the test deck (near Salem) is representative of the studded tire vehicle volumes at locations across the state that experience snowfall.
- ODOT has not determined whether the snow removal practices (such as the bit type used by the snowplows) at the test deck are representative of snow removal practices at other locations where durable pavement markings are used.
- ODOT has not set boundaries for the cross slope for ODOT test decks. Cross slope of pavement surface can substantially impact retroreflectivity readings (20% increase with increase in cross slope to 2% and 50% increase to 4% cross slope) and would therefore impact retroreflectivity measurements and subsequent decisions related to product adoption and useful service of life estimations.

4.2.3 ODOT QPL

The research project also identified two concerns related to the current ODOT QPL:

- Discrepancies between the performances of particular pavement marking materials across time by ODOT indicates there may have been changes in chemical composition of pavement marking materials. The chemical composition of the binder of durable pavement markings can impact durability and retroreflective performance of pavement markings. When products are place on the ODOT QPL the manufacturer is told that the product must maintain consistent chemical composition across time or notify ODOT so the product can be removed from the QPL. Whether or not manufacturers comply with this requirement is not known.
- The size and coating of beads used in durable pavement markings substantially impact retroreflective performance as does the application rate of beads. The ODOT QPL does

not currently include specifications for size, coating and application rates of beads during installation.

4.2.4 Expected FHWA Minimum Retroreflectivity Requirements

Since it is likely that there will be an FHWA rule on minimum retroreflectivity requirements, it is necessary for ODOT to review current practices and consider activities that will lead to compliance with such requirements. The challenge facing ODOT in meeting minimum retroreflectivity requirements for longitudinal pavement markings in 2010 is not unique. States such as Washington, Utah, and Pennsylvania use snowplows and allow studded tires on all or some of the network which results in extensive damage to pavement markings. UDOT and PennDOT have hosted several test decks over the last few years, offering the opportunity for ODOT to consider data from these test decks as part of the ODOT product approval and useful service of life estimation.

4.2.5 Raised Reflective Pavement Markers

The use of RRPMs and maintenance of these markers to where three or more are visible from any position along the particular longitudinal pavement marking during nighttime conditions offers consistent and improved wet-weather nighttime visibility of a longitudinal marking. The FHWA proposed rule waives the minimum retroreflectivity requirements for such locations. ODOT would therefore benefit from a review of current policies to determine whether wider use of RRPMs would be of benefit to ODOT in terms of maintenance and most importantly minimizing the financial burden of meeting the anticipated minimum retroreflectivity requirements.

4.3 RECOMMENDATIONS

Based on the results of the research project and the recent proposed rule making for minimum retroreflectivity levels for longitudinal pavement markings, the following recommendations are made:

1. ODOT should utilize the opportunities the NTPEP test decks offer by tracking pavement marking materials placed both on the ODOT and NTPEP test decks and utilizing the NTPEP results to identify materials that may be useful to ODOT. ODOT will benefit from the more extensive reviews completed at NTPEP test decks. Specific procedures should be added to the pavement marking approval process outlined in the document, Permanent Pavement Markings for Use on Oregon Department of Transportation (ODOT) Highways (Appendix E) , so that there is a consistently followed evaluation. NTPEP data, along with data collected at ODOT test decks can be used to determine useful service life.

2. ODOT should review the current test deck procedures prior to implementing the next test deck. In particular, the following items warrant consideration:

    - *Surface Preparation*. Prepare the pavement surface prior to installation to ensure that installation conditions are consistent with those encountered in the field.

- *Site Selection.* Since the cross slope of the pavement surface can substantially impact retroreflectivity readings (20% increase in retroreflectivity with an increase in cross slope up to 2% and a 50% increase with a 4% increase in cross slope) choose a site that considers this factor. It is further recommended that the cross slope of a particular test bed be recorded and included whenever reports of results from a particular test deck are presented or evaluated.

- *Installation.* Consider the following:

    - Group samples by material type (paint, durable, and high performance) on the test deck with each installation clearly marked.

    - To make a comparison between approved pavement marking materials and new materials, place a comparison sample pavement marking material on the test deck which can be used as a baseline to ensure that new materials perform as well or better.

    - Measure the initial installation thickness with needlepoint micrometers to the top of the binder material and record these measurements as part of the installation detail. Reject all samples exceeding the specified thickness.

    - Consistently apply ASTM International standards at the test deck.

    - Record the material (binder type) and detailed information about the beads including, but not limited to type, size, coating, whether integral or top dressed, embedment, and application rates. This information should be included as part of the description of materials on the conditional and approved QPL, i.e. these installations should be identified as "packages" and subsequently used as such if conditionally or fully approved.

- *Monitoring.* Consider the following:

    - Use ASTM International standards to consistently monitor samples.

    - Monitor samples at installation and at 30-day intervals until the end of the useful service life.

    - Analyze ODOT and NTPEP test deck results to determine useful service life by estimating time to failure (minimum retroreflectivity values) with the use of the Weibull distribution.

    - Use photo logging as part of documentation for durability performance of each sample during each monitoring visit.

    - Use median values rather than average values when combining observations taken by different reviewers on the same date.

- *General Guidance*.

    - Identify ten individuals within ODOT who can participate in the periodic review of the test deck. This will support regular review by a team of three by reducing the impact of scheduling difficulties. To support consistency across observations, provide training on the test deck evaluation procedures to these individuals.

    - Review and consider adoption of appropriate sections of the NTPEP Best Practices Manual for pavement marking test decks as part of the ODOT Test Deck process.

3. Due to the likelihood that rules regarding minimum retroreflectivity levels will take effect, ODOT will need to select and implement a maintenance procedure. The following approach is recommended:

    - Identify representative groups of material types, distinguishing between roadway type (interstates, two lane highways, multilane highways); urban and rural environment; geometric condition (tangent, curve); and climatic region (areas experiencing frequent snow during the wintertime and those areas not experiencing snow). Identify a sample of segments in each of the representative groups for monitoring.

    - Schedule calibrated visual nighttime inspections or consistent parameters visual nighttime inspection (MUTCD Maintenance Methods) at the sample segments at appropriate intervals

    - Consistently record results of visits.

    - Utilize results to schedule replacement of markings.

    The recommendation is based on an approach that will be practical with the anticipated four year implementation phase-in schedule for minimum retroreflectivity requirements and minimizing the effort and expense to ODOT to the highest extent possible.

4. To alleviate the burden of meeting the proposed FHWA minimum retroreflectivity requirements for pavement markings, ODOT should consider more extensive use of RRPMs

5. Develop a basic spreadsheet or program to facilitate processing the test deck results and subsequent approval or rejection of pavement marking samples from the test deck. The purpose of the software tool is to alleviate the effort by ODOT personnel and ensure consistency of analysis by different personnel. The software tool should allow ODOT to move towards being able to determine the useful service life of different pavement marking materials and will support compliance with FHWA minimum retroreflectivity requirements that are likely to be adopted in 2010 or 2011.

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APPENDIX A: LIST OF ACRONYMS

Acronym	Description
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ASTM International	Formerly known as the American Society for Testing and Materials
CAD	Computer-Aided Design
CARVE	Computer-Aided Road-Marking Visibility Evaluator
DOTs	Departments of Transportation
FHWA	Federal Highway Administration
MLT	Maintenance and Operations Leadership Team
MMA	Methyl methacrylate
MnDOT	Minnesota Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NJDOT	New Jersey Department of Transportation
NTPEP	National Transportation Product Evaluation Program
ODOT	Oregon Department of Transportation
PennDOT	Pennsylvania Department of Transportation
PMMS	Pavement Management Marking System
QPL	Qualified Products List (ODOT)
R	Relative Performance
RI	Refractive Index
R_L	Coefficient of Retroreflective Luminance
RL	Minimum Required Retroreflectivity
RRPMs	Raised Reflective Pavement Markers or Reflective Raised Pavement Markers
SSC	Statewide Striping Committee
TarVIP	Target Visibility Prediction software
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
US	United States
VDOT	Virginia Department of Transportation
WPMMS	Web-based Pavement Management Marking Systems
WSDOT	Washington State Department of Transportation

APPENDIX B:
LIST OF RELEVANT ASTM INTERNATIONAL STANDARDS

- D4505-05 Standard Specification for Preformed Retroreflective Pavement Marking Tape for Extended Service Life
- D4592-05 Standard Specification for Preformed Retroreflective Pavement Marking Tape for Limited Service Life
- D6628-03 Standard Specification for Color of Pavement Marking Materials
- Proposed: WK16773 Practice for Evaluating Retroreflectance of Pavement Markings Using Portable Hand-Operated Instruments
- Proposed: WK144 Specification for Wet Retroreflectance of Pavement Marking Materials
- Proposed: WK19195 Evaluating Retroreflective Pavement Markings Using Portable Hand-Operated Instruments
- Proposed: WK19471 Thermoplastic Pavement Marking Material for Use in Non-Snow Plow Areas
- D4061-94(2006) Standard Test Method for Retroreflectance of Horizontal Coatings
- E808-01(2009) Standard Practice for Describing Retroreflection
- E1710-05 Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer
- E2176-08 Standard Test Method for Measuring the Coefficient of Retroreflected Luminance of Pavement Markings in a Standard Condition of Continuous Wetting (RL-Rain)
- E2177-01 Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (RL) of Pavement Markings in a Standard Condition of Wetness
- E2302-03a Standard Test Method for Measurement of the Luminance Coefficient Under Diffuse Illumination of Pavement Marking Materials Using a Portable Reflectometer
- E2366-05 Standard Test Method for Measurement of Daytime Chromaticity of Pavement Marking Materials Using a Portable Reflection Colorimeter
- E2367-05 Standard Test Method for Measurement of Nighttime Chromaticity of Pavement Marking Materials Using a Portable Retroreflection Colorimeter
- E2540-08 Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 Degree Observation Angle
- Proposed: WK3833 Test Method for determination of the coefficient of retroreflection of pavement markings using a 30 meter geometry mobile retroreflectometer.
- Proposed: WK9050 Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 degree observation angle
- Proposed: WK19806 Measuring the Coefficient of Retroreflected Luminance of Pavement Markings in a Standard Condition of Continuous Wetting (RL-Rain)
- D711-89(2004) Standard Test Method for No-Pick-Up Time of Traffic Paint
- D713-90(2004) Standard Practice for Conducting Road Service Tests on Fluid Traffic Marking Materials
- D868-85(2003) Standard Test Method for Evaluating Degree of Bleeding of Traffic Paint
- D869-85(2004) Standard Test Method for Evaluating Degree of Settling of Paint
- D913-03e1 Standard Test Method for Evaluating Degree of Resistance to Wear of Traffic Paint
- D969-85(2003)e1 Standard Test Method for Laboratory Determination of Degree of Bleeding of Traffic Paint
- D1155-03 Standard Test Method for Roundness of Glass Spheres

- D1214-04 Standard Test Method for Sieve Analysis of Glass Spheres
- D1309-93(2004) Standard Test Method for Settling Properties of Traffic Paints During Storage
- D2205-85(2004) Standard Guide for Selection of Tests for Traffic Paints
- D2743-68(2004) Standard Practices for Uniformity of Traffic Paint Vehicle Solids by Spectroscopy and Gas Chromatography
- D2792-69(2004) Standard Test Method for Solvent and Fuel Resistance of Traffic Paint
- D4796-88(2004) Standard Test Method for Bond Strength of Thermoplastic Traffic Marking Materials
- D4797-88(2007) Standard Test Methods for Chemical and Gravimetric Analysis of White and Yellow Thermoplastic Traffic Marking Containing Lead Chromate and Titanium Dioxide
- D4960-08 Standard Test Method for Evaluation of Color for Thermoplastic Traffic Marking Materials
- D7307-06 Standard Practice for Sampling of Thermoplastic Traffic Marking Materials
- D7308-07 Standard Practice for Sample Preparation of Thermoplastic Traffic Marking Materials
- Proposed: WK22333 The Determination of Titanium Dioxide and Lead Chromate in Thermoplastic Pavement Marking Materials Using Instrumental X-ray Florescent (XRF) Techniques
- Proposed: WK23758 Standard Test Method for Measuring Gradation of Glass Beads Using a Flowing Stream Digital Image Analyzer
- D4505-05 Standard Specification for Preformed Retroreflective Pavement Marking Tape for Extended Service Life
- D4592-05 Standard Specification for Preformed Retroreflective Pavement Marking Tape for Limited Service Life
- D6628-03 Standard Specification for Color of Pavement Marking Materials
- Proposed: WK16773 Practice for Evaluating Retroreflectance of Pavement Markings Using Portable Hand-Operated Instruments
- Proposed: WK144 Specification for Wet Retroreflectance of Pavement Marking Materials
- Proposed: WK19195 Evaluating Retroreflective Pavement Markings Using Portable Hand-Operated Instruments
- Proposed: WK19471 Thermoplastic Pavement Marking Material for Use in Non-Snow Plow Areas

APPENDIX C: SUMMARY OF THE MUTCD PAVEMENT MARKING RETROREFLECTIVITY STANDARDS (APRIL 2010)

Summary of the MUTCD Pavement Marking Retroreflectivity Standard
April 2010
Excerpt from Publication No. FHWA-SA-10-015

This document may be modified as needed as a result of rule-making and will be re-issued concurrent to the Final Rule.

Pavement markings are an accepted method to communicate both the intended travel path and roadway alignment for drivers during day and nighttime conditions. To ensure consistent application of pavement markings, their characteristics and warranting criteria are described in the Manual on Uniform Traffic Control Devices (MUTCD).

The new MUTCD Section 3A.03 requires agencies to use a method designed to maintain longitudinal pavement markings to a minimum level of retroreflectivity outlined in Table 3A-1. The Federal Highway Administration (FHWA) believes that this change will promote safety while providing sufficient flexibility for agencies to choose a maintenance method that best matches their specific conditions.

The new MUTCD Section does not imply that an agency must measure every pavement marking. Rather, the new MUTCD Section describes methods that agencies can use to maintain pavement marking retroreflectivity at or above the minimum levels. Agencies can choose one of these methods or combine them. However, agencies must adopt a method that produces results which correspond to the values in Table 3A-1. Agencies are allowed to develop other appropriate methods based on engineering studies, as long as there is still a tie to the values in Table 3A-1.

Within the new MUTCD Section there are subtle but important distinctions that categorize pavement markings into three general types:

Not required to be retroreflective—These are pavement markings where ambient illumination assures adequate visibility or pavement markings that are needed only in the daytime (e.g. where access to a park may be daytime only). These pavement markings do not need to be maintained to minimum levels of retroreflectivity.

Required to be retroreflective, but not subject to minimum levels—All markings other than those discussed in the first bullet must be retroreflective, but some of these markings are not subject to the new minimum retroreflectivity levels. Examples of exceptions provided by the new MUTCD language include crosswalk markings, other transverse markings, words, symbols, arrows, etc. Some longitudinal lines are exempt from the new minimum retroreflectivity levels under certain conditions, such as presence of continuous roadway lighting or raised retroreflective pavement markers.

Subject to minimum retroreflectivity levels—These include the white and yellow longitudinal pavement markings that are required or recommended in the MUTCD, such as the center lines, edge lines, lane lines, and channelizing lines that the MUTCD says

shall or should be used above certain volumes or for certain roadway conditions.

The new MUTCD Section recognizes that there may be some pavement markings that do not meet the minimum retroreflectivity levels at a particular point in time (such as during winter months in northern climates, along some isolated horizontal curves, near driveways, etc). As long as the agency with jurisdiction is maintaining pavement markings in accordance with Section 3A.03 of the MUTCD, the agency will be considered to be in compliance.

This document introduces the new MUTCD Section, references existing MUTCD language, and it also describes methods that can be used to maintain pavement marking retroreflectivity at or above the MUTCD's new minimum maintained retroreflectivity levels.

The first revision to the 2009 MUTCD introduces a new section establishing a requirement to use a method designed to maintain minimum retroreflectivity levels for pavement markings. Agencies will have until [insert month and year - 4 years after Final Rule effective date] to establish and implement that pavement marking maintenance method. Agencies will have until [insert month and year- six years from the Final Rule effective date] to replace pavement markings that fail to meet the new regulations.

Compliance Dates:

Four years from date of Final Rule for implementation and continued use of a maintenance method that is designed to maintain pavement marking retroreflectivity at or above the established minimum levels.

Six years from date of Final Rule for replacement of pavement markings that are identified using the maintenance method as failing to meet the established minimum levels.

New MUTCD Section 3A.03 Maintaining Minimum Retroreflectivity of Longitudinal Pavement Markings

Standard:

Public agencies or officials having jurisdiction shall use a method designed to maintain retroreflectivity of the following white and yellow longitudinal pavement markings, at or above the minimum levels in Table 3A-1:

Center line markings on roads where they are required or recommended by Section 3B.01. This shall include any no-passing zone markings, longitudinal two-way left-turn lane markings, and yellow markings used to form flush medians on such roads.

Lane line markings on roads where they are required or recommended by Section 3B.04. This shall include any dotted lane lines, lane drop markings, and longitudinal preferential lane markings on such roads.

Edge line markings on roads where they are required or recommended by Section 3B.07. This shall include any channelizing lines delineating gores, divergences, or obstructions on such roads.

Any optional edge line markings that are used to qualify for the lower minimum retroreflectivity values in the "All other roads" row of Table 3A-1.

Support:

Compliance with the above Standard is achieved by having a method in place and using the method to maintain the minimum levels established in Table 3A-1. Provided that a method is being used, an agency or official having jurisdiction would be in compliance with the above Standard even if there are pavement markings that do not meet the minimum retroreflectivity levels at a particular location or at a particular point in time.

There are many factors for agencies to consider in developing a method of maintaining minimum pavement marking retroreflectivity including, but not limited to, winter weather, environmental conditions and pavement resurfacing.

Guidance:

Except for those pavement markings specifically identified in the Option below, one or more of the following methods, as described in the 2010 Edition of FHWA's "Summary of the MUTCD Pavement Marking Retroreflectivity Standard (see Section 1A.11)," should be used to maintain retroreflectivity of longitudinal pavement markings at or above the levels identified in Table 3A-1:

Calibrated Visual Nighttime Inspection – Prior to conducting a nighttime inspection from a moving vehicle and in conditions similar to nighttime field conditions, a trained inspector calibrates his eyes to pavement markings with known retroreflectivity levels at or above those in Table 3A-1. Pavement markings identified by the inspector to have retroreflectivity below the minimum levels are replaced.

Consistent Parameters Visual Nighttime Inspection – A trained inspector at least 60 years old conducts a nighttime inspection from a moving vehicle under parameters consistent with the supporting research. Pavement markings identified by the inspector to have retroreflectivity below the minimum levels are replaced.

Measured Retroreflectivity – Pavement marking retroreflectivity is measured using a retroreflectometer. Pavement markings with retroreflectivity levels below the minimums are replaced.

Service Life Based on Monitored Markings – Markings are replaced based on the monitored performance of similar in-service markings with similar placement characteristics. All pavement markings in a group/area/corridor are replaced when those in the representative monitored control set are near or at minimum retroreflectivity

levels. The control set markings are monitored on a regular basis by the visual nighttime inspection method, the measured retroreflectivity method, or both.

Blanket Replacement – All pavement markings in a group/area/corridor or of a given type are replaced at specific intervals. The replacement interval is based on when the shortest-life material in that group/area/corridor approaches the minimum retroreflectivity level. The interval is also based on historical retroreflectivity data for that group/area/corridor.

Other Methods – Other methods developed based on engineering studies that determine when markings are to be replaced based on the minimum levels in Table 3A-1.

Option:

Public agencies or officials having jurisdiction may exclude the following markings from their minimum pavement marking retroreflectivity maintenance method(s) and the minimum maintained pavement marking retroreflectivity levels, but not from any requirements in Section 3A.02 to be retroreflective.

Words, symbols, and arrows,

Crosswalks and other transverse markings,

Black markings used to enhance the contrast of pavement markings on a light colored pavement,

Diagonal or chevron markings within a neutral area of a flush median, shoulder, gore, divergence, or approach to an obstruction,

Dotted extension lines that extend a longitudinal line through an intersection or interchange area,

Curb markings,

Parking space markings, and

Shared use path markings.

Table 3A-1. Minimum Maintained Retroreflectivity Levels for Longitudinal Pavement Markings

	Posted Speed (mph)		
	≤30	35–50	≥55
Two-lane roads with centerline markings only_	n/a	100	250
All other roads_	n/a	50	100

Measured at standard 30-m geometry in units of mcd/m2/lux

Exceptions:

When RRPMs supplement or substitute for a longitudinal line (see Section 3B.13 and 3B.14), minimum pavement marking retroreflectivity levels are not applicable as long as the RRPMs are maintained so that at least 3 are visible from any position along that line during nighttime conditions.

When continuous roadway lighting assures that the markings are visible, minimum pavement marking retroreflectivity levels are not applicable.

Excerpts from Existing MUTCD Language Related to Minimum Retroreflectivity

Section 3A.02 Standardization of Application

Markings that must be visible at night shall be retroreflective unless ambient illumination assures that the markings are adequately visible. All markings on Interstate highways shall be retroreflective.

Section 3B.01 Yellow Centerline Pavement Markings and Warrants

Centerline markings shall be placed on all paved urban arterials and collectors that have a traveled way of 20 feet or more in width and an ADT of 6,000 vehicles per day or greater. Centerline markings shall also be placed on all paved two-way streets or highways that have three or more lanes for moving motor vehicle traffic.

Centerline markings should be placed on paved urban arterials and collectors that have a traveled way of 20 feet or more in width and an ADT of 4,000 vehicles per day or greater. Centerline markings should also be placed on all rural arterials and collectors that have a traveled way of 18 feet or more in width and an ADT of 3,000 vehicles per day or greater. Centerline markings should also be placed on other traveled ways where an engineering study indicates such a need.

Section 3B.04 White Lane Line Pavement Markings and Warrants

Lane line markings shall be used on all freeways and Interstate highways

Lane line markings should be used on all roadways that are intended to operate with two or more adjacent traffic lanes that have the same direction of travel, except as otherwise required for reversible lanes. Lane line markings should also be used at congested locations where the roadway will accommodate more traffic lanes with lane line markings than without the markings.

Section 3B.07 Warrants for Use of Edge Lines

Edge line markings shall be placed on paved streets or highways with the following characteristics:

Freeways;

Expressways; and

Rural arterials with a traveled way of 20 feet or more in width and an ADT of 6,000 vehicles per day or greater.

Edge line markings should be placed on paved streets or highways with the following characteristics:

Rural arterials and collectors with a traveled way of 20 feet or more in width and an ADT of 3,000 vehicles per day or greater.

At other paved streets and highways where an engineering study indicates a need for edge line markings.

MUTCD Maintenance Methods

More details on these methods can be found in report titled Methods for Maintaining Pavement Marking Retroreflectivity, which will be available at http://safety.fhwa.dot.gov/roadway_dept/night_visib. That report should be reviewed prior to using these methods.

A. Calibrated Visual Nighttime Inspection

This is one of two different versions of a visual inspection method. In this method, a trained inspector views "calibrated pavement markings" prior to conducting the nighttime inspection. Calibrated pavement markings have known retroreflectivity levels at or above minimum levels. These pavement markings are set up where the inspector can view them in a manner similar to actual nighttime field inspections. The inspector uses the visual appearance of the calibrated pavement markings to establish the evaluation threshold for that night's inspection activities. The following list provides

additional information on the use of this procedure:

Calibrated pavement markings can be markings on roadways open to public travel or markings in or near an agency's facility. They need to have retroreflectivity levels at or above the levels in Table 3A-1.

Calibrated pavement markings need to be applied and used in the same manner that nighttime inspections will occur. For example, white edge lines need to be on the right of the inspection vehicle and yellow center lines need to be on the left of the inspection vehicle. The calibrated pavement markings need to be long enough so that they can be viewed at typical viewing distances from the inspection vehicle traveling at typical speeds of the nighttime inspection.

The retroreflectivity levels of the calibrated pavement marking should be verified periodically with a retroreflectometer.

Conduct nighttime inspections from a passenger car (not a pickup or SUV) at normal operating speeds with good weather conditions (free of rain or fog and with dry pavement markings). Use low-beam headlamp illumination while minimizing interior vehicle lighting.

The inspector makes a judgment on whether actual roadway markings are above or below the retroreflectivity level of the calibration markings viewed at the beginning of that night's inspection.

B. Consistent Parameters Visual Nighttime Inspection

This is the second visual inspection method, and is based on similar factors that were used in the research to develop the minimum retroreflectivity levels. It is similar to the visual inspection method described above in that nighttime inspections are conducted from a passenger vehicle at normal operating speeds with good weather conditions (free of rain or fog and with dry pavement markings) using low-beam headlamp illumination while minimizing interior vehicle lighting. The difference is that calibrated markings are not necessary and no special equipment is needed as long as the following factors are satisfied.

Using a passenger car (not a pickup or SUV) to conduct the inspection.

Using a model year 2000 or newer vehicle for the inspection.

Using an inspector who is at least 60 years old.

The inspector makes a judgment on whether roadway markings are sufficient to meet their driving needs.

C. Measured Retroreflectivity

In this method the pavement marking retroreflectivity is measured and directly compared to the minimum levels in Table 3A-1. The retroreflectivity measurements can either be made with handheld devices or mobile devices, as long as they are measured using the standard 30-meter geometry. Inspectors should follow the instructions provided by the manufacturer to obtain reliable retroreflectivity readings, including periodic calibration of the equipment.

D. Service Life Based on Monitored Markings

In this method, pavement markings are replaced before they reach the end of their service life, which is when a representative sample of similar markings that are monitored through measurement or visual nighttime inspection have degraded to the retroreflectivity levels in Table 3A-1. This method would include a system for tracking similar groups of pavement markings based on color, type of materials, and other characteristics such as traffic volume. The representative sample must have similar in-service characteristics, rather than being placed at locations such as a maintenance yard or shoulder where they would not be subjected to similar wear.

E. Blanket Replacement

With this method, an agency replaces all of the pavement markings in an area, corridor, and/or of a given marking material type, at pre-selected specified time intervals based on the relevant expected service life (using levels in Table 3A-1). The replacement intervals are based on historical retroreflectivity data for specific roadways and types of marking material. The replacement intervals are based on when the shortest-life material in that group/area/corridor approaches the minimum retroreflectivity levels. This method typically requires that all of the designated pavement markings within a replacement area, or of the particular pavement markings type, be replaced, even if segments of markings were recently installed, following a resurfacing project, for instance.

F. Other Methods

Agencies can choose from the methods described on this page, combine them, or develop other methods based on engineering studies. It is important, however, that if an agency develops a different method, it must be based on an engineering study and must be based on the minimum levels in Table 3A-1.

APPENDIX D: RESPONSES TO STATE INTERVIEWS

State: PA

Date: 02/22/2010
Person Interviewed: Matthew Briggs
Email: mabriggs@state.pa.us
Tel. 717-783-6268

1. Do you use high performance pavement markings or durable pavement markings in
   a) New construction (please list type of products where appropriate – such as MMA etc.)
   Epoxy, Hot Thermoplastic, Cold Plastic, Pre-formed Thermoplastic, MMA, Polyurea, Polyester, and Wet-Reflective Tape.

   b) Re-marking of existing pavement markings (please list type of products where appropriate such as MMA etc.)
   We typically replace in-kind, as long as that product is meeting expectations and is still available.

2. Does your department have set guidelines that indicate where and when the use of particular pavement marking materials is more appropriate than others?
   Yes, our guidelines are found in Publication 46, Section 3.2.1.

3. Test Deck
   i) Does your department have a test deck or any other evaluation process for new materials?
      Yes, there is a NTPEP Test Deck in Pennsylvania.
   ii) Is any formal documentation available on your test deck? (solicitation, a detailed description of the test deck procedures and evaluation process)
      The NTPEP Office would have to be contacted. My office is not directly linked to the NTPEP.
   iii) What is the duration of your test deck? If it is not a fixed time period, what criteria do you use to determine how long the test deck should be monitored?
      Three-years, as determined by NTPEP.
   iv) Briefly describe the monitoring process on your test deck.
      The Test Deck is monitored by our Materials and Testing Lab upon installation, and every two months (excluding our winter maintenance season – roughly from November thru March).

4. Does your department have a conditional approval process for new materials? Is any documentation available on it?
   An experimental process exists, but it is rarely used.

5. Does your state use results from the NTPEP program to support your decision-making or approval process?
   Only from the Pennsylvania NTPEP Test Deck.

6. Does your department use any in-service evaluation process for these materials after the materials are conditionally or fully accepted for use on your highways?
   A majority of the product approvals come from the NTPEP Test Deck in Pennsylvania.

7. How does your department ensure/verify that the materials are applied correctly on projects and that the material meets particular quality standards? i.e. are any laboratory tests performed on the material and do inspectors perform any testing or measurement on site?
   The construction inspection crews use an inspection form to confirm amount of beads and paint used. And a wet-film thickness test is also done. Field samples are taken and the lab conduct tests on the material. The contractors also supply a Certification of Materials to each project.

8. Are studded tires allowed on your highways? If so, what types of studs (i.e. metal, ceramic)
   Yes. Studded snow tires are permissible from November 1st to April 15th.

9. In areas where there is snow, do you place certain requirements on the type of blade/shoe for snow plows to protect the durable markings?
   A variety of different shoes are used. The state has a policy to get down to the bare pavement so we try to stay away from bigger beads because of that.

10. Does your department measure the retroreflectivity of new markings immediately after installation on your highway?
    Initial readings during construction, and random measurements of District-installed lines.

11. Do you regularly measure retroreflectivity of installations i.e. 1, 3, or 6 months over an extended period of time? If so, to what extent and how do you analyze the data?
    No.

12. Are any night-time retroreflectivity observations made? How?
    No.

13. Is your department doing any wet-weather retroreflectivity testing on existing installations?
    No.

14. Are there any new or ongoing research studies or activities taking place in your state on wet-weather retroreflectivity of pavement markings or test decks?
    No.

15. Has your state implemented or considered alternative methods to improve nighttime wet weather visibility of longitudinal markings? (such as raised pavement markers for example?)
    Yes, Pennsylvania has installed and continues to maintain snowplowable RPMs on all of our Interstates. In addition, our District Offices also maintain SRPMs in other high-volume locations. Our annual program is between $3 to $4 million.

State: Utah

Date: 3/1/10
Person Interviewed: Ken Berg
Email: kenberg@utah.gov
Tel. 801 965 4321

1. Do you use high performance pavement markings or durable pavement markings in
   a) New construction (please list type of products where appropriate such as MMA etc.)
   Long lines:
   - Tape□rolled in on asphalt, grooved in on concrete
   - Epoxy (ungrooved on concrete, warranty contract) on I□15 in Salt Lake valley
   - Thermoplastic messages—i.e. stop bars, arrows, crosswalks—
     grooved in on concrete

   b) Re□marking of existing pavement markings (please list type of products where appro
   priate – such as MMA etc.)
   High□build waterborne used for maintenance.

2. Does your department have set guidelines that indicate where and when the use of particular pavement marking materials is more appropriate than others?
   Yes.

3. Test Deck
   a) Does your department have a test deck or any other evaluation process for new materials?
      Yes.
   b) Is any formal documentation available on your test deck? (solicitation, a detailed description of the test deck procedures and evaluation process)
      We've had several test decks over the years, some better documented and reported than others. We do have general guidelines for all test decks.
   c) What is the duration of your test deck? If it is not a fixed time period, what criteria do you use to determine how long the test deck should be monitored?
      Three years is the initial duration and may be longer or shorter depending on the performance of the material
   d) Briefly describe the monitoring process on your test deck.
      We write a work plan, collect and evaluate data and write reports.

4. Does your department use any in-service evaluation process for these materials after the materials are conditionally or fully accepted for use on your highways? Maintenance forces use a subjective rating system. Nothing quantitative is used.

5. How does your department ensure/verify that the materials are applied correctly on projects and that the material meets particular quality standards? i.e. are any laboratory tests performed on the material and do inspectors perform any testing or measurement on site?
   Laboratory tests on waterborne binders are performed. No field tests are done by inspectors on any marking types.

6. Are studded tires allowed on your highways? If so, what types of studs (i.e. metal, ceramic).
   Yes, metal studs allowed in winter months only.

7. In areas where there is snow, do you place certain requirements on the type of blade/shoe for snow plows to protect the durable markings?
   No. Keeping roads as clear as possible is the priority with no regard for pavement markings.

8. Does your department measure the retroreflectivity of new markings immediately after installation on your highway? Only if installed on a planned test deck. No measurements are taken in normal production work.

9. Do you regularly measure retroreflectivity of installations i.e. 1, 3, or 6 months over an extended period of time? If so, to what extent and how do you analyze the data? (See #10)
   On a test deck, retro measurements are typically taken in the spring, after the salt and dirt have been washed by spring rains, and in the fall before the first snow fall. Retro data is analyzed in a spreadsheet with decaying exponential curve fitting used to predict time to failure at 100 mcd.

10. Are any night-time retroreflectivity observations made? How? Yes. We have used hand held meters and a video camera in a vehicle.

11. Is your department doing any wet-weather retroreflectivity testing on existing installations?
    Yes. We are evaluating larger bead sizes in waterborne paint grooved in on concrete.

12. Does your department have a conditional approval process for new materials? Is any documentation available on it?

    New products are tested and may be used depending on performance, need, etc.

13. Does your state use results from the NTPEP program to support your decision□making or approval process?
    Currently NTPEP is part of all the data used, but we rely on our own field test decks more than anything else.

14. Are there any new or ongoing research studies or activities taking place in your state on wet-weather retroreflectivity of pavement markings or test decks?
    Yes. See # 13. We have one installation and are planning a second test deck this spring.

15. Has your state implemented or considered alternative methods to improve nighttime wet weather visibility of longitudinal markings? (such as raised pavement markers for example?)
    Yes. See #13 and #14. We can't used RPM's because of plowing but are always looking for a better solution to get some kind of marker below the pavement surface that works and is maintainable.

State: Washington State Department of Transportation
Date: February 18, 2010
Person Interviewed: Edwin Lagergren
Email: lagerge@wsdot.wa.gov
Tel. (360) 705-7284

1. Do you use high performance pavement markings or durable pavement markings in
a) New construction (please list type of products where appropriate – such as MMA etc.)?
WSDOT used profiled MMA as a lane line on Interstates and other divided highways in western Washington. WSDOT uses MMA and thermoplastic for transverse and symbol markings. WSDOT uses grooved 3M tape for some Interstate lane lines in Eastern Washington.

b) Re-marking of existing pavement markings (please list type of products where appropriate – such as MMA etc.)?
All remarking of long line markings in done in standard (15 mil) waterborne paint. WSDOT has plastic crews for transverse and symbol markings in the three western Washington regions.

2. Does your department have set guidelines that indicate where and when the use of particular pavement marking materials is more appropriate than others?
The WSDOT Design Manual 1030 has minimal guidelines for pavement marking material types. The Region Traffic Office has a striping plan they use to specify pavement marking materials on contracts.

3. Test Deck

a) Does your department have a test deck or any other evaluation process for new materials?
WSDOT has partnered with ODOT in the past on test decks. ODOT did most of the work. Now WSDOT uses NTPEP or other State testing programs to approve new materials. We are proposing a plan to use successful performance in other States as criteria as well. The last pavement marking test WSDOT did was the I-90 Pavement Marking Material Test in 2004 to 2008. It was a one time test.

b) Is any formal documentation available on your test deck? (solicitation, a detailed description of the test deck procedures and evaluation process)
I-90 was a long line deck. Year one results were presented at TRB in 2006 Session #491. I published the complete 4 year report on CD in 2008. Some markings are still functioning a supplementary unpublished report was done in 2009 and I will take another look later this spring (2010).

c) What is the duration of your test deck? If it is not a fixed time period, what criteria do you use to determine how long the test deck should be monitored?
We set a retroreflectivity of 100 and a durability of 50% as the failure criteria. To be fair to all markings, it is as long as it takes.

d) Briefly describe the monitoring process on your test deck.
We monitored initially, mid-December, mid-February, and April of the first winter. We then monitored in September and April the next year. Years 3, 4, 5 and 6 were evaluated in April.

4. Does your department have a conditional approval process for new materials? Is any documentation available on it?
WSDOT does not.

5. Does your state use results from the NTPEP program to support your decision-making or approval process?
Yes.

6. Does your department use any in-service evaluation process for these materials after the materials are conditionally or fully accepted for use on your highways?
Don't have this process.

7. How does your department ensure/verify that the materials are applied correctly on projects and that the material meets particular quality standards? i.e. are any laboratory tests performed on the material and do inspectors perform any testing or measurement on site?
Actually, no samples and very minimal testing on most projects.

8. Are studded tires allowed on your highways? If so, what types of studs (i.e. metal, ceramic)
WSDOT allows studs. I believe they are "light" studs, whatever that means.

9. In areas where there is snow, do you place certain requirements on the type of blade/shoe for snow plows to protect the durable markings?
No. We are using more deicer.

10. Does your department measure the retroreflectivity of new markings immediately after installation on your highway?
No.

11. Do you regularly measure retroreflectivity of installations i.e. 1, 3, or 6 months over an extended period of time? If so, to what extent and how do you analyze the data?
No.

12. Are any night-time retroreflectivity observations made? How?
Region striping crews do some of this in planning the striping season.

13. Is your department doing any wet-weather retroreflectivity testing on existing installations?
No.

14. Are there any new or ongoing research studies or activities taking place in your state on wet-weather retroreflectivity of pavement markings or test decks?
No. WSDOT has allowed some wet weather tests to be put down at no additional cost. These tests do not seem to work.

15. Has your state implemented or considered alternative methods to improve nighttime wet weather visibility of longitudinal markings? (such as raised pavement markers for example?)
WSDOT uses both Raised and Recessed retroreflective pavement markers.

APPENDIX E:
PERMANENT PAVEMENT MARKINGS FOR USE ON OREGON DEPARTMENT OF TRANSPORTATION (ODOT) HIGHWAYS

Oregon
Theodore R. Kulongoski, Governor

Department of Transportation
Office of Maintenance & Operations
800 Airport Road SE
Salem OR 97301-4792
Telephone (503) 986-3000
FAX (503) 986-3032

Permanent Pavement Markings for use on Oregon Department of Transportation (ODOT) Highways

The purpose of this document is to outline the process required to authorize the usage of permanent pavement marking materials on ODOT highways. Pavement marking binder materials used for both construction projects and in-house maintenance activities must be on the ODOT Qualified Products List (QPL). Reflective components will be determined by the product manufacturer. More information regarding the QPL is outlined on website: http://www.oregon.gov/ODOT/HWY/CONSTRUCTION/QPL/QPIndex.shtml

We currently have four categories of permanent pavement markings; waterborne paint, high performance pavement markings, durable pavement markings, and pavement markers. The process for the approved use of pavement markers will not be addressed in this document. The other three categories of pavement markings require successful evaluation on an ODOT Pavement Marking Testdeck. The pavement markings are applied transverse to the highway in accordance with ASTM D713-90. Durable pavement markings require a three year manufacturer warranty for surface applied thermoplastic and four year warranty for inlaid thermoplastic and all other durable materials. High performance pavement markings require a one year manufacturer warranty. Complete warranty information can be found in 'Oregon Standard Specifications for Construction' section 00850.75. This document is also on-line on website: http://www.oregon.gov/ODOT/HWY/SPECS/index.shtml

Process for Inclusion of Products on the Test Deck

The pavement marking material manufacturer (manufacturer) must submit all documentation required for inclusion on the QPL and the product must perform successfully on a testdeck. The documentation required for the QPL is;

Preliminary Information for Product Evaluation Form

Copies of test reports showing compliance with the Materials Specifications

Copies of Brochures, including pictures

MSDS (including primers if necessary)

Limitations of Product or Installations

Installation Recommendations

Place each product on an ODOT Testdeck for evaluation

In addition to the above requirements for all pavement marking materials high performance and durable pavement markings also require;

Signed Warranty Acceptance Statement

Copy of Contractor Certification program

Submit two samples of each color, and shape, approximately 8" long

The manufacturer must indicate on the, 'Preliminary Information for Product Evaluation' form which application method or type they wish their product approved for. Depending on which method chosen additional testing may be required. This information can also be found on website: http://www.oregon.gov/ODOT/HWY/CONSTRUCTION/QPL/QPIndex.shtml

Specification and Application Criteria

ODOT will announce future pavement marking testdecks and notify manufacturers so they will have the opportunity to participate with their products. The following specifications, test methods, and standards in effect on the opening date of the testdeck announcement form a part of the specification where referenced: *(ODOT at their discretion may limit the number of samples of similar products from one manufacturer)*

AASHTO M247; ASTM D93; ASTM D713; ASTM D913; ASTM D1210; ASTM D1729; ASTM D2621; ASTM D2697; ASTM D2805; ASTM D3335; ASTM D3718; ASTM D3960; ASTM E70; EPA 3052; EPA 6010C; EPA 6020; and FTMS 4053

There may be other test methods and specifications specifically described in this document. The manufacturer will submit test results from an independent laboratory indicating the materials comply with the listed specifications.

Independent laboratory test requirements for waterborne paint are as follows:

Viscosity at 25°C	100 KU max.	ASTM D562
Fineness of Grind, Hegman	3 min.	ASTM D1210
Laboratory dry to no pickup time @ 380 µm wet film thickness (no beads) @ 50% humidity	10 minutes max.	ASTM D711
Flash Point, °C min	37 min.	ASTM D93

Pigment content, % by weight	68% max.	ASTM D3723
Non volatile vehicle,	36% min.	FTMS 4053
% by weight		
Total solids by volume	60% min.	ASTM D2697
Directional Reflectance		
@ 380 μm wet film thickness		
White	88% min.	ASTM D2805

Contrast Ratio		
@ 380 μm wet film thickness		
White	98% min.	ASTM D2805
Yellow	96% min.	ASTM D2805
Freeze Thaw	5 cycles min.	ASTM D2243
Volatile Organic Compound	less than	ASTM D3960
(VOC)	150 g per liter	
pH	9.5 min.	ASTM E70
Chromium	shall be negative	ASTM D3718

The binder shall be 100% acrylic when tested in accordance with ASTM D2621.

Color. Paint draw-downs shall be prepared in accordance with ASTM E97. The color of the yellow samples will be compared to the PR-1 chart. They shall meet 33538 Federal Yellow.

Scrub Resistance. The paint shall pass a minimum of 500 cycles when tested in accordance with ASTM D2486.

Static Heat Stability. Put 450 mL of paint in a 473 mL (one pint) lined container, close the container, seal it with tape, and put in an oven maintained at 135°F ± 1°F for 7 days. Equilibrate the paint at standard conditions and mix thoroughly with gentle stirring. Examine paint for livering and hard settling and determine viscosity. The paint shall show no increase in viscosity greater than 10 KU over the viscosity at 77°F nor any coagulation, lumps, or coarse particles.

Field test performed by ODOT as the first requirement of a testdeck,

No-track time	90 seconds max.

No-Track Time. The paint shall dry to a no-track condition in no more than 90 seconds when applied at 15 mils wet film thickness on dry pavement temperature of 50°F to 100°F and maximum 85% relative humidity, with 5-6 pounds of glass beads per gallon of paint. "No-Track" shall be the time required for the line to withstand the running of a standard automobile over the line at a speed of approximately 40 mph simulating a passing procedure, without tracking of the reflectorized line when viewed from a distance of 50 feet downstream.

Independent laboratory test requirements for high performance and durable pavement markings are as follows:

Volatile Organic Compound (VOC)	less than 1.2518 lbs per gallon	ASTM D3960
Chromium	No Spec	ASTM D3718
Total Lead	No Spec	EPA 6020

Color. The color of the yellow samples will be compared to the PR-1 chart. They shall meet 33538 Federal Yellow.

The reflective materials used shall conform to the following heavy metal requirements,

Arsenic	less than 200 ppm (parts per million)	EPA 3052
Antimony	less than 200 ppm	EPA 3052
Lead	less than 200 ppm	EPA 3052

The testdeck procedure will be in accordance with ASTM D 713-90, "Standard Practice for Conducting Road Tests on Fluid Traffic Marking Materials", except as modified herein. A panel organized by ODOT will evaluate each formulation for durability, color, and night visibility performance.

Type and Location of Pavement for Tests - The products will be applied on portland cement concrete and asphaltic cement concrete pavements. The planned test site will be determined on an annual basis. *(Testdeck placement will be regularly scheduled for mid-summers, bi-annually performed on even years. ODOT will provide traffic control during the placement and evaluations of testdecks. The testdeck evaluation team will consist of members from the ODOT Pavement Marking Committee.)*

Application Procedure

Waterborne Paint - The material will be applied transverse to the roadway. Stripes will be 4 inches wide with a wet film thickness of 15 mils. Standard M247 Type 1 beads with an AC110

coating will be placed at 5-6 pounds per gallon of paint. Two stripes of each formulation will be applied on bare pavement of both portland cement concrete and asphalt cement concrete. The standard ODOT waterborne paint currently on the maintenance contract will be placed on the deck and act as "control". Performance of all submitted samples will be expected to meet or exceed the performance of the "control". Panels of each formulation will be taken for documentation and for comparison on the appearance evaluation.

High Performance Pavement Markings - The material will be applied transverse to the roadway. Stripes will be 4 inches wide with a wet film thickness as submitted in writing by the manufacturer with the original bid paperwork. Two stripes of each formulation will be applied on bare pavement of both portland cement concrete and asphalt cement concrete. The beads and bead application rate shall be those recommended by the manufacturer. Beads shall be placed with an automatic system. The manufacturer in the presence of an ODOT official will determine the actual thickness as placed. Panels of each formulation will be taken for documentation and for comparison on the appearance evaluation unless submitted with the bid documentation.

Durable Pavement Markings - The material will be applied transverse to the roadway. Stripes will be 4 inches wide with a wet film thickness of 120 mils plus or minus 10 mils. Two stripes of each formulation will be applied on bare pavement of both portland cement concrete and asphalt cement concrete. Tape and preformed thermoplastic do not need to conform to this thickness requirement and will be the manufactured thickness. The manufacturer may recommend a variance in the application thickness, but it must be in writing and submitted with the original bid paperwork. ODOT must approve any variance. The beads and bead application rate shall be those recommended by the manufacturer. Beads shall be placed with an automatic system. Panels of each formulation will be taken for documentation and for comparison on the appearance evaluation unless submitted with the bid documentation.

Evaluation criteria for pavement marking materials on the testdeck will be as follows; *(Evaluation schedule for high performance and durable pavement markings will be monthly throughout the life of the testdeck or until products fail. The schedule for waterborne paint will be more often. If weather does not permit night time readings the dates can be slightly modified. During rainy times the visual evaluations may be done by the evaluation team and the retroreflectivity readings taken at the soonest possible chance.)*

Appearance is the complete impression conveyed when the material surface is viewed at a distance of at least 10 feet, before any detailed inspection has been made. It takes into account changes in the color of the surface under consideration, taking into account changes due to yellowing, bleeding, darkening, fading, dirt collection, mold growth, etc.

Durability is a measure of the material remaining on the pavement or substrate. This determination will be made by evaluating an area extending 6 inches each side of the center point of either wheel track. The evaluation will be made in accordance with Test Method D713-90. The rating by each panel member will be averaged. Failure is defined as when there is less than 50% of the material left on the pavement or substrate within the evaluation area.

Night visibility will be conducted using a Delta LTL-X hand held retroreflectometer. Five measurements will be taken between the wheel tracks of each line. The average of readings from

all lines for each product will be used. Failure is defined as when the measurement is less than 100 millicandellas per lux per square meter.

Color will be determined by using the PR-1 Chart, 33538 Federal Yellow. The determination will be made without preliminary washing or other modification of the surface of the test lines.

Evaluation Procedure – ODOT will install the waterborne paint and monitor the installation of high performance and durables pavement markings.

Waterborne Traffic Paint - Each stripe will be evaluated for 12 months or until a failure occurs. Any paint sample that fails laboratory testing, field track testing, or fails to perform at least as well as the control paint will be disqualified from the process. All products that pass the laboratory testing, field track testing, and perform at least as well as the control will be approved for placement on the QPL but the manufacturer must have both a white and yellow sample pass the testing for the products to be placed on the QPL.

High Performance Pavement Markings - Each stripe will be evaluated for 24 months or until a failure occurs. Any pavement marking sample that fails laboratory testing or fails any of the field tests within the 24 month period may be considered a failure and disqualified from the process. All products that pass the laboratory testing, field tests, and perform at least as well as other high performance pavement marking materials will be approved for placement on the QPL but the manufacturer must have both a white and yellow sample pass the testing for the products to be placed on the QPL.

Durable Pavement Marking - Each stripe will be evaluated for 24 months or until a failure occurs. Any pavement marking sample that fails laboratory testing or fails any of the field tests within the 24 month period may be considered a failure and disqualified from the process. All products that pass the laboratory testing, field tests, and perform at least as well as other durable pavement marking materials of the same type will be approved for placement on the QPL but the manufacturer must have both a white and yellow sample pass the testing for the products to be placed on the QPL. The only exception to this is for material to be used for legends because only white products are used so no yellow material is required for the legend categories.

The manufacturer will indicate in their QPL submittal which application method or type they want their product approved for. If they chose a profile marking they must verify with additional testing the ability of their product to profile. ODOT will choose a location and arrange with the manufacturer a time to perform this additional testing. *(A status report will be provided to the participants when their products fail the evaluation or annually.)*

Conditional Approval

Conditional approval of products for the QPL may occur for high performance and durable pavement markings. There are three options for gaining conditional approval;

1) Pavement marking products that have been evaluated on testdecks done in other states to include both state managed as well as National Transportation Product Evaluation Program (NTPEP) testdecks. This documentation will be evaluated and if approved by ODOT will be

granted conditional approval once the manufacturer provides all the ODOT QPL required paperwork as listed above in, **'<u>Process for Inclusion of Products on the Test Deck.</u>'** ***(****The evaluation team will consist of the five Region Pavement Marking Managers and the Statewide Pavement Marking Coordinator who will determine approval based off of value to the Agency and Public.)*

2) ODOT may approve a demonstration of pavement marking products if Agency determines a benefit to the State. Manufacturer will submit request to the Statewide Pavement Marking Coordinator (SPMC) using a New Products form included below and all the ODOT QPL required paperwork. This demonstration will be evaluated for a minimum of one year. After acceptable performance of the product conditional approval will be granted. ***(****The evaluation team will consist of the five Region Pavement Marking Managers and the Statewide Pavement Marking Coordinator. The team and will base their decision off of the following: For longline application a minimum of 2000' of all lines will be provided by the manufacturer. The manufacturer will provide all initial testing consistent with the construction requirements for the product category and ODOT may verify these test results. The longline projects will be tested by the laserlux van approximately annually after installation. After the first year the performance levels will be at least 225 mcd for white markings and 200 mcd for yellow markings. For legend materials a minimum of five locations will be selected by ODOT. The materials will be provided by the manufacturer along with all initial testing consistent with the construction requirements for the product category and ODOT may verify the test results. The legend material when tested with a Delta LTL-X will have a minimum of 150 mcd and show little to no wear after a year from installation. Products already listed as qualified on the QPL will use the demonstration option to gain approval for different application method(s) or type. Any product(s) for any category that fail the testing will be placed on the ODOT QPL rejected list. ODOT will limit the location and amount of conditional test sites. These options may be eliminated by ODOT if deemed appropriate.*

3) For materials placed on an ODOT testdeck and after at least six months of evaluation where the material performs as well as other materials in the same category ODOT may grant conditional acceptance on the QPL based on needs of the Agency.

<u>Usage of Conditionally Approved Products</u>

Once a pavement marking has been granted conditional approval by one of the above three options the material **may be used on construction projects**. Products that are conditionally qualified on the QPL are only available for contractors to use for the categories and application methods they are approved. To use a conditionally approved product the manufacturer will make a request to the construction Project Manager for the product to be used on a specific construction project. This request will be made a minimum of one week prior to the scheduled application and accepted on a case by case basis in proactive collaboration with the Region Pavement Marking Manager. ODOT will consider many factors to help with this decision. The factors include, but are not limited to, the size of the project, traffic volume, location, type of highway, climatic area, and what type of pavement markings are on the adjacent sections. ODOT will track the usage of conditional products and evaluate the performance of these pavement markings for those projects. These reviews are used as additional information along with the mandatory ODOT testdeck information to make the decision on product acceptance.

Products that do not perform acceptably, for the required time, on the testdeck and/or in field applications will be removed from the Conditional List. The list will be reviewed and updated on a yearly basis.

Conditionally approved pavement marking products must successfully pass the evaluation on an ODOT pavement marking testdeck to become qualified on the QPL. Conditional usage is not required but used along with the mandatory testdeck data to assist with the decision. Products that perform successfully on and ODOT pavement marking testdeck and have successful reviews from conditional projects will be approved for the QPL. Once approved by ODOT and the manufacturer has submitted the QPL documentation the product will have qualified status on the QPL.

APPENDIX F:
CHARTER OF THE ODOT STATEWIDE STRIPING COMMITTEE

Highway Division
Statewide Striping Committee
Adopted: April 9, 2009

CHARTER & OPERATING GUIDELINES

PURPOSE

The Statewide Striping Committee (SSC) provides strategic planning, oversight, specification review/development, and guidance for the ODOT pavement marking program. The SSC's key goals are:

- To develop and execute a strategic plan for pavement marking (including durable products) – plan to be approved by the Maintenance and Operations Leadership Team (MLT).
- To promote statewide consistency through relevant practice, procedures, standards, and specifications.
- To provide technical expertise to insure that the ODOT pavement marking program is implemented in a cost effective and efficient manner.

These goals are met through the following responsibilities and activities:

- Evaluate and test new products as they become available.
- Develop, support, monitor and evaluate the effectiveness of a sensible and sustainable pavement marking program. Ensure that evaluation criteria are simple and understood.
- Periodically review the program to insure that the developed program continues to meet customer needs.
- Make recommendations to MLT on funding levels.
- Make recommendations to MLT on new equipment purchases that support the approved program.
- Review, monitor, and make recommendations for specification changes.

AUTHORITY

Authority is established under the authority of MLT. The authority of the SSC is only for those items delegated directly to the committee by MLT.

MEMBERSHIP AND ROLES

Core Membership:
The SSC's core membership includes a management representative from each Region (Region Pavement Marking Program Managers), a District Manager, two representatives from the Office of Maintenance, a representative from Traffic, and a representative from Project Delivery (Construction Project Manager). See Attachment A for current member names.
Leadership: The *District Manager* chairs SSC and is charged with managing the team's work plan and meeting agendas, and presiding at each meeting.

Support:
Administrative support is provided by the Statewide Office of Maintenance and Operations.

MEMBERSHIP EXPECTATIONS AND RESPONSIBILITIES

Members are expected to:

- Attend all meetings or send an appropriate representative.
- Participate in sub-team work as needed. Take on a fair share of work assignments and follow through.
- Be prompt in attending meetings and in meeting deadlines for assignments, agenda items, and/or follow-up work. Be well prepared for planned meeting discussions.
- Raise issues and fully engage in discussions and decision-making processes in a positive and productive way.
- Aim for consensus by sharing a viewpoint and working the issue constructively without being a roadblock or simply giving in. Provide different opinions respectfully and respect the opinions of others.
- Make decisions that are in the best interest of the agency, not a particular region or unit. Support decisions made by the team through actions and words.
- Seek the appropriate level of input for decisions. Assess impacts to other parts of the organization and address at other leadership teams as appropriate.
- Communicate decisions and information, appropriately and in a timely fashion, with represented region, section or other respective business area, and with any others who need to know.
- If serving as a liaison on another team, be a communication conduit between the two teams.
- Use discretion when sharing information from meetings and honor confidences or confidential material.
- Keep the discussion focused on the topic presented.

RELATIONSHIP TO OTHER TEAMS

Attachment B demonstrates the relationship between the SSC, MLT, and other teams under the authority of MLT.

DECISION-MAKING

The SSC relies on collaboration and partnering between all members with a goal of making decisions that support the overall good of ODOT. A consensus of all team members is highly desired for team decisions and recommendations. Whenever appropriate, SSC will solicit input on decisions from MLT and their sub-teams, and/or other teams within ODOT. A formal review process will be used for any new direction, policy, procedure or process. Issues that cannot be resolved by the SSC will be resolved by the District Manager representative if within positional authority otherwise the issue will be raised to MLT.

MEETING & AGENDA SCHEDULE

SSC meetings are typically held quarterly on the day prior to MLT, typically the second Wednesday of the month, from 1pm – 4pm. Meetings are to be held in January, April, July, and October. Additional meetings may be held as needed.

Agendas and meeting materials will be prepared according to the following schedule: all agenda topic proposals, handouts, and materials due **1 week prior** to meeting – any exceptions need to be discussed with the SSC chair. Final agenda and meeting materials sent out by the **Monday prior** to the meeting.

There may be occasions when sub-teams are established to address specific issues and will need to meet more frequently. There may also be occasions when the SSC needs to extend or adjust the typical meeting schedule to accommodate peak work items, holiday schedules, or other uncommon situations.

Visitors will be invited as topics and issues necessitate. The SSC welcomes requests to attend or requests to enter topics into the agenda. The SSC also reserves the right to hold "Executive Sessions" with core members when necessary to discuss highly confidential or sensitive issues.

WORK PLAN

The SSC's work plan is developed collaboratively and is adopted by a consensus of all team members. The work plan identifies decisions, issues and initiatives under consideration by the SSC, along with the responsible team member, current status, and anticipated completion date for each. A decision log will be used to track decisions made. The SSC will provide an annual work-plan report the first of each new calendar year.

To add items to an existing work plan, the issue or initiative must:

- Have statewide significance/impact
- Have action required, achieve a desired product and/or resolve a problem
- Have a champion and an issues brief prepared for SSC consensus to add

PERFORMANCE INDICATORS

On a yearly basis, the SSC will review specific work plan items which are aligned with and support the mission and goals of MLT. In addition, the SSC will conduct periodic reviews of the pavement marking program, system, resources, and structure to continuously ensure the agency is positioned for current and future success in delivering the program.

DOCUMENT CHANGE ACTIVITY

The following is a record of the changes that have occurred on this document from the time of its original approval.

PAGE	CHANGE DESCRIPTION	AUTHOR	DATE

ATTACHMENT A

Highway Division
Statewide Striping Committee

CURRENT MEMBERS
AS OF 2-10-2009

Core		
Mike Buchanan*	District 13 Manager/MLT Representative	541-963-8406
Joel Fry	Office of Maintenance	503-986-4485
Benny Grant	Office of Maintenance	503-986-3054
Chad Gordon	Region 1 Traffic Line Manager	503-731-8322
Mark Friesen	Region 2 Traffic Services Manager	503-373-1300
Randy Camp	Region 3 Traffic Line/Sign Crew Manager	541-957-3651
Rolon Williams	Region 4 Pavement Marking Program Manager	541-388-6474
Pete Caldwell	Region 5 Pavement Marking Program Manager	541-963-1587
Katie Johnson	Traffic Devices Engineer	503-986-3610
Shane Ottosen	Salem Construction Project Manager	503-986-2698
Support/Resources/Partners		
Leann McCormick	Administrative Support	503-986-4443
Nick Fortey	FHWA	503-587-4721
June Ross	Research Unit	503-986-2846
Mike Dunning	Construction and Materials Section	503-986-3059

* Chair for SSC

ATTACHMENT A

Highway Division
Statewide Striping Committee

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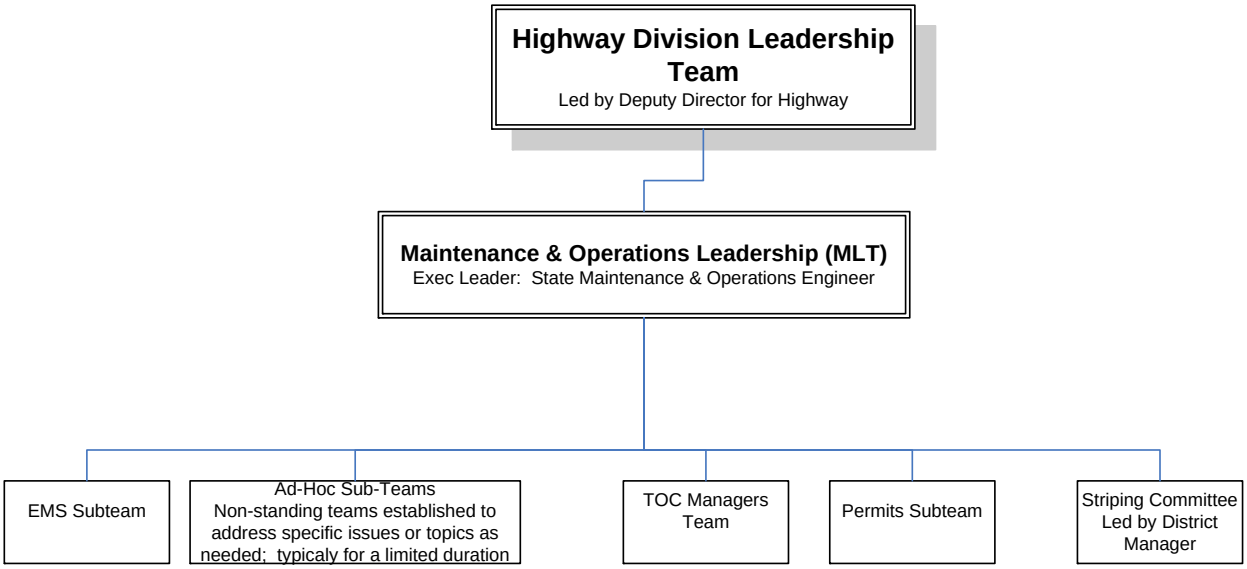
Mike Dunning	Construction and Materials Section	503-986-3059

* Chair for SSC

ATTACHMENT B



APPENDIX G:
EXAMPLE OF SOLICITATION FOR SAMPLES FROM ODOT

Issued Date: July 12, 2006 **OREGON DEPARTMENT OF TRANSPORTATION**

SOLICITATION FOR SAMPLES

BID NO.:	**22715**	*BID CLOSING DATE:*	**July 28, 2006**	*TIME:*	**5:00 p.m.**
DESCRIPTION:	**2006 Pavement Marking Material Test Deck**				
PROGRAM MANAGER:	**Joel Fry**	*PHONE:*	**503-986-4485**	*FAX:*	**503-986-3032**
		E-MAIL:	**joel.d.fry@odot.state.or.us**		

BIDS will be received until the BID CLOSING DATE and TIME noted above by the ODOT OFFICE OF MAINTENANCE at:

OREGON DEPARTMENT OF TRANSPORTATION
OFFICE OF MAINTENANCE
800 AIRPORT ROAD SE
SALEM, OREGON 97301-4792

SINGLE POINT OF CONTACT: There will be only one point of contact for this Solicitation for Samples. The contact point is the ODOT Office of Maintenance, and the contact person is the Program Manager listed above.

Any questions or issues that may arise shall be directed to the Program Manager listed above. ODOT's official response to any questions or requests will be through direct letters or the addendum process.

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SCOPE

This solicitation is to generate a Qualified Product Listing for a variety of non-leaded pavement marking materials suitable for asphaltic and Portland cement concrete pavements. At this time, we are testing durable marking materials and products considered as "Other". The "Other" products should perform better than waterborne paint but do not meet the Oregon Department of Transportation (State) Durable Pavement Marking criteria. State will accept samples and place them on a test deck for evaluation. Products that pass this evaluation will be considered for placement on the State' Qualified Products List (QPL). The Washington State Department of Transportation (WSDOT) will be participating in this evaluation of non-leaded pavement marking materials. Products that pass this evaluation will be considered for addition to the WSDOT Qualified Products List. The test deck is scheduled for August 22 and 23, 2006.

APPLICABLE SPECIFICATIONS

The following specifications, test methods, and standards in effect on the opening date of the Solicitation for Samples form a part of this specification where referenced:

AASHTO M247; ASTM D93; ASTM D713; ASTM D913; ASTM D1210; ASTM D1729; ASTM D2621; ASTM D2697; ASTM D2805; ASTM D3335; ASTM D3718; ASTM D3960; ASTM E70; EPA 6020; and FTMS 4053

There may be other test methods and specifications specifically described in this document.

DURABLE MARKING MATERIALS

State requires a manufacturer' warranty for pavement marking materials listed as a durable product. State will accept other types of materials for evaluation during this process. We are looking for products that offer a road service life in long line applications of 4 to 10 years. For details of the warranty requirements see Attachment 1 below.

Test Requirements - Lab

Volatile Organic Compound (VOC)	less than 1.2518 lbs per gallon	ASTM D3960
Chromium	No Spec	ASTM D3718
Total Lead	No Spec	EPA 6020

Color. The color of the yellow samples will be compared to the PR-1 chart. They shall meet 33538 Federal Yellow.

Road Service Test

Two transverse lines of a length, width, and film thickness as designated by State will be applied at ambient temperature on highway surfaces for both asphaltic concrete and Portland cement concrete at locations to be selected by State for the test. Only those samples meeting all the requirements in this section will be used in the Road Service Test. The Bidder will be required to place these materials on the test deck under the direct supervision of State. State shall be the sole judge of methods, equipment, rates of application, and test evaluation. It is expected that a two-year evaluation of the durables will be performed.

OTHER MARKING MATERIALS

State will accept other types of materials for evaluation during this process. The "Other" markings are materials that do not fit into the waterborne paint or durable pavement markings categories. We are looking for products that offer a road service life in long line applications of 2 to 3 years.

Test Requirements - Lab

Volatile Organic Compound (VOC)	less than 1.2518 lbs per gallon	ASTM D3960
Chromium	No Spec	ASTM D3718
Total Lead	No Spec	EPA 6020

Color. The color of the yellow samples will be compared to the PR-1 chart. They shall meet 33538 Federal Yellow.

Road Service Test

Two transverse lines of a length, width, and film thickness as designated by manufacturer will be applied at ambient temperature on highway surfaces for both asphaltic concrete and Portland cement concrete at locations to be selected by State for the test. Only those samples meeting all the requirements in this section will be used in the Road Service Test. The Bidder will be required to place these materials on the test deck under the direct supervision of State. State shall be the sole judge of methods, equipment, rates of application, and test evaluation. It is expected that a two-year evaluation of the "Other" markings will be performed.

Products that pass this evaluation will be considered for placement on the State' QPL and are described in the State Construction Specification 00864 High Performance Pavement Makrings. The results of these tests will be furnished to the manufacturer at the conclusion of the test upon request. There is no promise that we will purchase or use any of the products tested under this category.

SAMPLES, SUBMITTALS, AND TESTING FEES

Two samples of each product will be necessary at the time of bid. After laboratory and road tests have been completed a final evaluation of the samples will be made.

Submittals

Data Sheets. As part of the bid package the bidder shall provide two sets of the following: Material Safety Data Sheet (MSDS), brochures, and specification data sheet describing the product (including reflective glass elements) in detail, any limitations of the product, and detailed information regarding applications procedures.

Certified Test Results. As part of the bid package the manufacturer will submit 2 copies of certified independent test results including all of the tests listed above. State will test the products when and where it deems appropriate. Failure to meet specifications at any time constitutes reason for removal from the QPL and rejection of any bids associated with this product.

Administrative Fees. There will be an administrative fee assessed to all bidders for expenses incurred during laboratory and field testing of the pavement marking samples and will include the expense of providing traffic control during application and evaluation of the pavement markings. Bidders may submit more than one formulation for testing provided separate bid documents and testing fees are submitted. The fee is $900 for each durable material or "Other" material. Matching yellow and white samples will be considered two samples for the purpose of the fee schedule. Checks should be made payable to the Oregon Department of Transportation. The testing fees are intended to cover all costs incurred by the State to place, evaluate, and report the test deck products. Any remaining funds will be returned to suppliers when the evaluation and reporting is complete.

TRAFFIC TEST DECK INSTALLATION AND EVALUATION PROCEDURE

This procedure is in accordance with ASTM D 713-90, "Standard Practice for Conducting Road Tests on Fluid Traffic Marking Materials", except as modified herein. A panel organized by State will evaluate each formulation for durability, color, and night visibility performance.

Type and Location of Pavement for Tests - The products will be applied on portland cement concrete and asphaltic cement concrete pavements. The planned test site will be on Oregon Route OR 22 just east of Salem Oregon.

Application Procedure

Durable Pavement Markings - The pavement marking will be applied transverse to the roadway with a powered applicator. Stripes will be 4 inches wide with a wet film thickness of 90 mils plus or minus 10 mils. The manufacturer may recommend a variance in the application thickness, but it must be in writing and submitted with the original bid paperwork. State must approve any variance. The beads and bead application rate shall be those recommended by the manufacturer. Beads shall be placed with an automatic system.

Other Pavement Markings - The material will be applied transverse to the roadway with a powered applicator. Stripes will be 4 inches wide with a wet film thickness submitted in writing by the manufacturer with the original bid paperwork. The beads and bead application rate shall be those recommended by the manufacturer. Beads shall be placed with an automatic system. The manufacturer in the presence of State official will determine the actual thickness as placed.

Evaluation Procedure – State will monitor the installation.

Durable Pavement Marking - Each stripe will be evaluated for 24 months or until a failure occurs. Any pavement marking sample that fails laboratory testing or fails any of the field tests within the 24 month period will be considered a failure and disqualified from the process.

Other Pavement Markings - Each stripe will be evaluated for 24 months or until a failure occurs.

Durability is a measure of the material remaining on the pavement or substrate. This determination will be made by evaluating an area extending 6 inches each side of the center point of either wheel track. The evaluation will be made in accordance with Test Method D913-88. The rating by each panel member will be averaged. Failure is defined as when there is less than 50% of the material left on the pavement or substrate.

Color will be determined by using the PR-1 Chart, 33538 Federal Yellow. The determination will be made without preliminary washing or other modification of the surface of the test lines.

Night visibility will be conducted using a hand held retroreflectometer like the Mirolux 12, Mirolux 30, Ecolux, LTL 2000, or similar device. Failure is defined as when the measurement is less than 100 millicandellas per lux per square meter. Measurements will be taken between the wheel tracks. The average of readings from all lines for each product will be used.

CONTACT PERSON

Joel Fry
ODOT - Office of Maintenance
800 Airport Road SE
Salem OR 97301-4792
Phone: 503 986-4485

ATTACHMENT 1

Oregon Department of Transportation
Durable Pavement Marking Warranty Requirements

Warranty - ODOT requires a manufacturer' warranty for durable pavement marking materials. Prior to placement on the QPL, the respective manufacturer will have to approve our warranty requirements. The warranty information is listed below for information only at this point, and is subject to change at any time.

Long Line Application

Long Lines - The warranty for durable long lines is listed in Section 00862.75 and 00851.75 of State' 'Oregon Standard Specifications for Construction'. It requires the contractor to provide a manufacturer' warranty according to the following:

For surface-mounted thermoplastic materials, provide a 3-year manufacturer' warranty that all markings will stay in place and will maintain a minimum retroreflectivity of 150 millicandellas for white and 125 millicandellas for yellow.

For surface-mounted methyl methacrylate materials, provide a 4-year manufacturer' warranty that all markings will stay in place and will maintain a minimum retroreflectivity of 150 millicandellas for white and 125 millicandellas for yellow.

For inlaid or grooved in tape materials, provide a 4-year manufacturer' warranty that all markings will stay in place and will maintain a minimum retroreflectivity of 150 millicandellas for white and 125 millicandellas for yellow.

For inlaid methyl methacrylate and thermoplastic materials, provide a 4-year manufacturer' warranty that all markings will stay in place and will maintain a minimum retroreflectivity of 150 millicandellas for white and 125 millicandellas for yellow.

The Warranty period will start on the date State accepts the work and authorizes final payment.

If reflectivity becomes a concern at any time during the warranty period, State will measure the retroreflectivity of the area in question, using a Mirolux 12, Mirolux 30, Ecolux, LTL 2000, or similar device. The surfaces of the roadway will not be cleaned in preparation for taking readings.

The manufacturer will be required to repair or replace (at the discretion of State) all markings that drop below the required minimum retroreflectivity during the warranty period, within 6 months of request to do so.

For the purpose of the warranty, a cumulative 5% or greater loss of line due to non-adhesion on any 300 foot segment of marking will constitute failure of the material in that segment.

Legend Marking Applicaton

Legends – The warranty for legends, including cross walks, stop bars, and other symbols is listed in Section 00850.75 of State' 'Oregon Standard Specifications for Construction'. It requires the contractor to furnish a manufacturer' warranty, signed by the manufacturer' representative, that all markings will stay in place, maintain their color, and maintain a minimum retroreflectivity of 100 millicandellas for an 18-month period. The in-place pavement markings are to have stability in color over the service life to provide color contrast with the pavement. Failure of the material to maintain color stability will be considered a complete failure of the material on that legend. Replace with specification materials any pavement markings failing to bond to the substrate surface during the warranty period.

The warranty period will start on the date State accepts the work and authorizes final payment for this item.

If the retroreflectivity becomes a concern at any time during the warranty period, State will measure the retroreflectivity for compliance, with a Mirolux 12, Mirolux 30, Ecolux, LTL 2000, or other similar device. Each legend will be tested separately at several random locations. The wheel tracks will be measured and averaged separately. State will choose the exact locations for the retroreflectivity test(s). Clean areas of obvious contamination and remove loose debris prior to testing.

The retroreflectivity shall not drop below 100 millicandelas during this warranty period. If just the wheel tracks become deficient during this period, replace the parts that have low retroreflectivity. If a larger section has low readings, replace the entire legend. Repair markings that drop below the required minimum retroreflectivity during the warranty period. Perform this repair work when weather permits, and within six months of request to do so. At the discretion of State, temporary pavement markings may be required to protect traffic before repairs can be made, and this will be at the contractor' expense.

Other Pavement Marking Material Products

State is asking for a warranty on products in the "Other" category that follow the criteria of the State' Construction Specification 00864 High Performance Pavement Markings.

For surface-mounted "other" materials provide a 1-year manufacturer' warranty that all markings will stay in place and will maintain a minimum retroreflectivity of 150 millicandellas for white and 125 millicandellas for yellow.