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Evaluation of Hardened Paint Pavement Markings

Arizona Department of Transportation Research Center

ADOT

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16. Abstract

The objective of this study was to obtain and analyze relevant technical and performance data of various pavement marking products to determine which products can be used to stripe various roadway surfaces and to withstand the spectrum of Arizona weather, ranging from intense ultraviolet exposure to abrasion from snowplow blades. Data gathering consisted of a survey of state deparments of transportation in nearby states with similar climates and a search of the National Transportation Product Evaluation Program (NTPEP) DataMine 3.0 for relevant pavement marking performance data.

The study found a number of practices to improve marking performance from the four state departments of transportation that participated in the survey, as well as from a review of ADOT's specifications. The recommended practices for ADOT to consider include: recessing markings at elevations above 4,000 feet where snow is likely to occur, using thicker thermoplastic markings on roadways with surface treatments, and decreasing the bead application rate required in the specifications for epoxy markings at elevations above 4,000 feet. The NTPEP data analysis along with a calculation and comparison of the equivalent annual uniform cost (EAUC) of each of the five analyzed products (epoxy, polyurea, thermoplastic, urethane, methyl methacrylate) provided answers on which products provide the longest service lives and which have the lowest annualized cost. Thermoplastic markings had the longest service life in both colder and warmer climates. Thermoplastic also had the lowest annualized cost, and epoxy had the second lowest.

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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	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	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 (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Contents

ABBREVIATIONS AND ACRONYMS LIST

AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
APL	Approved Products List
ASTM	American Society for Testing and Materials (now ASTM International)
CDOT	Colorado Department of Transportation
CIE	Commision Internationale de l'Eclairage
DOT	department of transportation
EAUC	equivalent uniform annual cost
ESL	end of service life
FL	Florida
lf	linear foot
lx	lux
mcd	millicandela
MMA	methyl methacrylate
MN	Minnesota
NMDOT	New Mexico Department of Transportation
NPV	net present value
NTPEP	National Transportation Product Evaluation Program
PA	Pennsylvania
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation

EXECUTIVE SUMMARY

PURPOSE

The Arizona Department of Transportation (ADOT) initiated this study to acquire more knowledge on the performance of various pavement marking products and to learn about the successful practices and policies of other state agencies. This information was then synthesized to assist ADOT with identifying potential changes for improving the service lives of the state's roadway markings. ADOT's current practice is to use epoxy pavement markings on roadways at elevations above 4,000 feet, where snow removal is common in winter months, and then to maintain with water-based paint. Roadways below 4,000 feet are striped with either hot-sprayed thermoplastic or preformed thermoplastic tape.

In recent years, ADOT has experienced a shorter than expected service life from several marking applications. In particular, epoxy pavement marking systems are failing after two years of service and failing even faster on chip-sealed roadways. The purpose of this study was to determine which of five pavement marking products can be used to stripe various roadway surfaces while withstanding the spectrum of Arizona conditions, ranging from intense ultraviolet light exposure to abrasion from snowplow blades. The five products were epoxy, polyurea, thermoplastic, urethane, and methyl methacrylate (MMA) Data gathering consisted of two parts:

1) Having selected neighboring states with similar climates, a survey of those state departments of transportation and their practices (Colorado, New Mexico, Texas and Utah departments of transportation responded)

2) A search of the National Transportation Product Evaluation Program (NTPEP) DataMine 3.0 for relevant pavement marking performance data

FINDINGS

The study found a number of practices from neighboring state departments of transportation (DOTs) to improve marking performance. The four states that participated in this survey are facing similar challenges to Arizona in pavement marking management. The methods they have used to increase material performance are listed below. The state DOTs using these methods are listed in parentheses.

- Developing glass bead gradations to optimize performance for specific materials through field testing (Colorado, New Mexico, Utah).
- Recessing marking material in a groove extends marking service life (Colorado, New Mexico, Utah).
- Using thicker wet film thicknesses of paint and thermoplastic markings can increase marking performance (Texas).
- Requiring pavement marking products to provide proof of performance through NTPEP test results or local field evaluation testing (Colorado, Texas).
- Using minimum initial retroreflectivity and/or initial durability specifications for durable markings sets a performance goal for material suppliers New Mexico, Texas). A higher initial

performance does not guarantee better life-cycle performance, but the testing will identify some instances of poor installation practices.

- Adding accelerated weathering test requirements or tighter daytime chromaticity requirements to material specifications, primarily for epoxy, promotes better color performance (Colorado, New Mexico, Texas).
- Defining a minimum retroreflectivity for end of service life helps ensure roadways are restriped as needed (Colorado, Utah).

The NTPEP data analysis, along with a calculation of the equivalent annual uniform cost (EAUC) of each of the five products (epoxy, polyurea, thermoplastic, urethane, and MMA), provided answers on which products provide the longest service lives and which have the lowest annualized cost. While the data from all NTPEP performance metrics (retroreflectivity, durability, and color) were analyzed, only retroreflectivity was used to determine product service life. The NTPEP period of evaluation is 36 months, and most products were still performing well at the end of the evaluation period. So service lives were projected using deterioration rates at the end of the 36-month period. An end of service life threshold was set at a retroreflectivity of 100 mcd/m^2/lux. All products had an estimated service life between four and eight years, but thermoplastic had the longest service life in both colder and warmer climates. Thermoplastic had the lowest EAUC, and epoxy had the second lowest. With the longer service life and the lowest annualized cost, thermoplastic provides the best return on investment.

RECOMMENDATIONS

Recommendations were provided on the optimum marking types, and suggestions were made for improved ADOT marking performance. Optimum marking materials are those that are compatible with a site, provide an appropriate service life, and are cost effective. Based on the NTPEP retroreflectivity data and EAUC comparisons, thermoplastic marking materials are the optimum marking of the five types. Epoxy marking materials appear to be the next best return on investment. Both marking systems are the products that ADOT is currently using.

Based on the responses from the four state DOTs that participated in the survey and on the review of ADOT's specifications, the following suggestions are provided for ADOT to consider:

- Recess the markings in pavement in areas with snowfall, specifically the locations at elevations above 4,000 feet. Utah, Colorado, and New Mexico stated that recessing markings extends their service lives, and Utah reported that it doubles the marking's life.
- Use thicker thermosplastic markings (100 mil thickness) on roadways with surface treatments, such as chip seals. The thicker marking is needed to fill the gaps between the small aggregates (chips) on the pavement surface. With the gaps filled, the beads will have a more uniform surface to bond to and therefore be more visible.
- Decrease the bead application rate (quantities) for epoxy markings in locations above 4,000 feet. The application rates in the current specifications are too high, causing the beads to "flood" the line and prevent light from entering and reflecting from the beads.
- Continue to require 70 percent true spheres or higher in marking specifications. Small increases in percent roundness can provide large increases in retroreflectivity.

CHAPTER 1. INTRODUCTION

The Arizona Department of Transportation (ADOT) uses a range of different pavement marking systems. Selection of the type of marking system typically depends on the elevation where the markings are to be placed. Roadways at an elevation above 4,000 feet, where snow removal is common in winter months, are typically striped with epoxy and maintained with water-based paint. Roadways below 4,000 feet are striped with either hot-sprayed thermoplastic or preformed thermoplastic tape.

In recent years, ADOT has experienced a shorter-than-expected service life from several marking applications. In particular, epoxy pavement marking systems are failing after two years of service and failing even faster on chip-sealed roadways. These failures require increased restriping in the face of decreasing maintenance budgets. Therefore, ADOT desires a solution that will provide the state with pavement markings with longer service lives.

Accordingly, the objective of this study was to obtain and analyze relevant technical and performance data of various pavement marking products to determine which products can be used to stripe various roadway surfaces and to withstand the spectrum of Arizona conditions, ranging from intense ultraviolet light exposure to abrasion from snowplow blades. Data gathering consisted of two parts:

1) Having selected neighboring states with similar climates, a survey of those state departments of transportation and their practices (Colorado, New Mexico, Texas and Utah departments of transportation responded)

2) A search of the National Transportation Product Evaluation Program (NTPEP) DataMine 3.0 for relevant pavement marking performance data

The research team synthesized the gathered data and provided ADOT with recommended updates to the state's pavement marking specifications. These recommendations considered pavement marking performance (retroreflectivity, color, and durability, where possible), reflective media, costs, pavement surface type, and region/climate of the state.

CHAPTER 2. DATA GATHERING SUMMARY

SURVEY OF NEIGHBORING STATES

The research team developed a list of survey questions for selected states near Arizona. (Appendix A contains the final list of questions.) The primary objectives of the survey were to gather each state's experience with various types of pavement marking products and to learn more about its pavement marking practices. The questions were grouped into three categories:

1. Marking Material and Placement
2. Climate and Environmental Factors
3. Marking Management and Performance-Based Specifications

The state departments of transportation (DOTs) in nearby states were contacted because it was expected that, having similar climatic and geological conditions, their experiences and practices would be most relevant to ADOT. The six selected states were California, Colorado, Nevada, New Mexico, Texas, and Utah. The appropriate contacts were identified. In some cases the contact could complete the entire survey, while in others that person coordinated a response from their department of transportation (DOT). Four of the six state DOTs (all but California and Nevada) responded to the survey. Table 1 lists the responding state DOTs and the primary contact in each.

Table 1. State DOTs Responding to Pavement Marking Survey and Corresponding Contacts

State DOT	Title of Corresponding Contact
Colorado	Pavement Design Program Manager
New Mexico	State Maintenance Engineer
Texas	Construction - Coatings and Traffic Materials Branch
Utah	Maintenance Methods Engineer

Appendix B consists of each state's response to the survey questions. Chapter 3 analyzes these responses.

NTPEP DATAMINE SEARCH

The role of the AASHTO (American Association of State Highway and Transportation Officials) NTPEP is to provide a source of independent data for many products that are used for construction and maintenance of America's roadways. Pavement marking products are one of those product types, and every year NTPEP installs a new test deck of various pavement marking systems submitted by manufacturers for evaluation. The pavement markings on these test decks are typically evaluated for a period of three years or less. Measured performance data are eventually saved to NTPEP's DataMine, an online repository of data that is available to anyone. The database has tools for performing queries to assist with analyzing current and past NTPEP evaluations. The research team accessed the DataMine and

pulled data from the three pavement marking test decks completed just before the beginning of this study. The locations and installation years of these test decks are:

1. Minnesota – 2010
2. Pennsylvania – 2011
3. Florida – 2012

Results from the Minnesota and Pennsylvania test decks are expected to be representative of ADOT roadways above 4,000 feet in elevation, where snow removal occurs in winter. The Florida test site is expected to be more representative of ADOT roadways below 4,000 feet, where snowfall typically doesn't occur. (However, Florida typically receives more rainfall than Arizona.)

The types of pavement marking systems represented on these test decks included waterborne and solvent-borne paints, thermoplastics, tapes, epoxies, polyureas, urethanes, and methyl methacrylates (MMAs). All products were placed as transverse markings across the width of the test lane, and all products were placed on both asphalt and concrete pavement surfaces. The metrics used to evaluate product performance included retroreflectivity, durability, and color. Chapter 3 provides an analysis of these metrics.

CHAPTER 3. RESULTS OF DATA ANALYSIS

SURVEY RESULTS FROM ARIZONA'S NEIGHBORING STATES

Contacts from Colorado, New Mexico, Texas, and Utah DOTs provided responses to the survey questions developed for Chapter 2. The majority of the responses answered the survey questions completely, and references to relevant specification documents were often provided. However, New Mexico's submittal omitted or generalized some responses, and at least one response did not concur with specifications published on the New Mexico Department of Transportation (NMDOT) website. A follow-up email was sent to the New Mexico contact seeking clarification, but no response was received. The following three subsections provide details of the states' responses to questions from the corresponding three sections of the survey: Marking Material and Placement, Climate and Environmental Factors, and Marking Management and Performance-Based Specifications.

Marking Material and Placement

Each state has pavement marking material and placement specifications in its state specification documents. The document links provided in the survey submittals and others located during data searches are listed in the References section of this report. Since some of these documents are quite large, a quick-reference list with the relevant section numbers is provided below.

Reference List of Relevant State DOT Pavement Marking Specifications

1. ***Colorado:***

   Colorado Department of Transportation (CDOT) Standard Specifications for Road and Bridge Construction (https://www.codot.gov/business/designsupport/cdot-construction-specifications/2017-construction-standard-specs/2017-specs-book/standard-specifications-2017-final.pdf/view)
   - Pavement Marking Installation – Section 627
   - Pavement Marking Materials – Section 708, 713

2. ***New Mexico:***

   NMDOT Design Manual: Section 910, Signing and Pavement Markings (http://dot.state.nm.us/content/dam/nmdot/Infrastructure/DesignManual/0910_Signing_and_Striping.pdf)
   - Pavement Marking Planning – Section 910.5

   NMDOT Standard Specifications for Highway and Bridge Construction (http://dot.state.nm.us/content/dam/nmdot/Plans_Specs_Estimates/2014_Specs_For_Highway_And_Bridge_Construction.pdf)
   - Pavement Markings – Section 704

3. ***Texas:***

   Texas Department of Transportation (TxDOT) Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges (http://ftp.dot.state.tx.us/pub/txdot-info/des/spec-book-1114.pdf)
   - Retroreflectorized Pavement Markings – Section 666
   - Prefabricated Pavement Markings – Section 668

   TxDOT Departmental Materials Specifications (http://ftp.dot.state.tx.us/pub/txdot-info/cst/DMS/8000_series/pdfs/)
   - DMS-8200, Traffic Paint
   - DMS-8220, Hot Applied Thermoplastic
   - DMS-8240, Permanent Prefabricated Pavement Markings
   - DMS-8290, Glass Traffic Beads

4. ***Utah:***

   Utah Department of Transportation (UDOT) Standard Specifications for Road and Bridge Construction (https://www.udot.utah.gov/main/uconowner.gf?n=31730316757114651)
   - Pavement Marking Paint – Section 02765
   - Pavement Marking Materials (Warranty Specification) – Section 02768

Survey Questions 1 and 2 were as follows:

1. What pavement marking products does your state use and what products are on your state's Approved Products List for pavement markings?
   What are the acceptance criteria, lab tests, standards, or policies to which the products must adhere?
   What is each product's expected service life?
2. What are typical material and installation costs or typical installed costs for the marking products listed in Question #1? Please indicate the marking line widths and thicknesses associated with these costs.

Responses to survey Questions 1 and 2 are summarized in Table 2. The table lists the preferred marking materials from each state in descending order of frequency of use along with estimated end of service life, approximate costs, stripe width, and required wet film thickness.

Table 2. Primary Pavement Marking Materials Data from State DOT Survey

State	Marking Material	Estimated End of Service Life (ESL) (years)	Typical Material / Installation Cost	Stripe Width (inches)	Wet Film Thickness (mils)
Colorado	Hi-Build Paint	*1-2	$25/gal	4	24
	Modified Epoxy	*3-5	$55/gal	4	18
	Preformed Plastic Tape	*6-8	$9.50/sf	4	N/A
	Preformed Thermoplastic	*4-6	$9.00/sf	Not provided	N/A
New Mexico	Hi-Build Paint	varies	$0.09/lf	6	Not provided
	Thermoplastic	varies	Not provided	Not provided	Not provided
	Tape	varies	Not provided	Not provided	N/A
Texas	Thermoplastic	3-4	$0.27/lf	averaged	Not provided
	Acrylic Latex Paint	1-2	$0.12/lf	averaged	Not provided
	Epoxy	4-5	$0.86/lf	averaged	Not provided
	Preformed Tape	4-5	$6.75/lf	averaged	N/A
Utah	Waterborne Paint	1-2	$0.11/lft ($22.00/gal)	4	22
	Recessed 3M™ 380 Tape	6 at low elevation 4 at high elevation	$2.30/lf	4	N/A

*Reduce ESL by half for high elevations.

As expected, paints were reported as having the shortest estimated service life but were also the least expensive. Three of the four states use paint most frequently. The TxDOT contact responded that the state places more thermoplastic than paint. The material service life and cost information provided by TxDOT shows that the state's annualized cost per linear foot (lft) of thermoplastic is comparable to that

of paint. Both Colorado and Utah reported different material service lives depending on the roadway's elevation.

Survey Question 1 also asked about product acceptance criteria. Submitted answers and supporting details from specification documents are provided in the summary below.

Colorado

- Acceptance criteria for addition to the Approved Products List (APL) require a two-year field evaluation compared to an adjacently placed, approved product in the category as a baseline. A certified test report from an independent lab showing that the product meets Colorado specifications is also required.
- Contractors must use materials from the APL and provide a Certificate of Compliance from the manufacturer prior to start of work.

New Mexico (*NMDOT Specifications for Highway and Bridge Construction, 2014)*

- Materials should be on the APL, which requires certified test results from an independent laboratory and a letter from the manufacturer to prove the material meets New Mexico specifications.
- Before work, contractors must provide a Certificate of Compliance and documentation that the State Materials Bureau has tested the batch of materials being used (Section 704.2.1.1).
- Thermoplastic material requirements must include a letter of certification from the manufacturer with each batch, certifying that the material meets NMDOT thermoplastic specifications (Section 704.2.5.1).

Texas

- Materials should be on the Material Producer List, which requires manufacturer test reports showing that the material meets specifications. The Materials and Pavements Section of the Construction Division performs any tests required to verify manufacturer and material conformance. (*Texas Department of Transportation Departmental Materials Specifications: DMS-8200*)
- Epoxy products require a one-year TxDOT test deck that meets the following minimum performance: white: 250 mcd/m2/lx, yellow: 175 mcd/m2/lx
- Prefabricated tape must meet the following minimum performance on a two-year NTPEP test deck: white: 200 mcd/m2/lx, yellow: 150 mcd/m2/lx

Utah

- Durable markings (tape and thermoplastic) require a manufacturer's bonded warranty.
- Waterborne paint suppliers are prequalified based on the state's standard specification.
- Utah does not use an approved products list.

Survey Questions 3 through 5 request details about glass bead use on thermoplastic, epoxy, and paint. Table 3 summarizes the responses regarding bead type, bead application, and performance rating for each material. Additional survey responses about successes and failures are listed by material type below. All liquid markings have beads dropped on them while wet. Thermoplastic markings often have glass bead mixed in, referred to as intermix, but may have beads dropped on them.

Thermoplastic

- Colorado – "When applying the top coating of beads you need to load it up."
- Texas – "Achieving minimum retroreflectivity is highly dependent on the thickness of applied material."

Epoxy

- Colorado – "Field testing to determine what combination of beads and application rates work for Colorado and proper application."
- Texas – "Generally do not have issues with retroreflectivity on epoxy pavement markings."

Paint

- Colorado – "Field testing to determine what combination of beads and application rates work for Colorado and proper application."
- Texas – "The thicker you can apply the traffic paint the better."
- Utah – "The key is getting the right thickness and good bead distribution."

Table 3. State DOT Survey Data on Glass Bead Use for Pavement Marking

State	Material Type	Bead Performance Rating (1-7)	Glass Bead Type & Application				
			Type 1	Type 2	Type 3	Type 4	State Blend
Colorado	Thermoplastic	5.5	Intermix and drop-on				
	Epoxy	7					Drop-on[3]
	Paint	6					Drop-on[4]
New Mexico	Thermoplastic[1]	6	Intermix				Drop-on
	Epoxy[2]	6	Drop-on				
	Paint	5	Drop-on				
Texas	Thermoplastic	5	Intermix	Drop-on	Drop-on		
	Epoxy	6	Drop-on			Drop-on	
	Paint	4		Drop-on	Drop-on		
Utah	Paint	6					Drop-on

1. New Mexico responded drop-on application only for thermoplastic, but state specification requires intermix and drop-on.
2. New Mexico responded single drop only for epoxy but in Question 4.c indicated the use of double-drop.
3. Colorado specifies specific state blend for epoxy markings.
4. Colorado specifies specific state blend for paint markings.

The standard specification for glass beads used in pavement markings is AASHTO M 247. However, most states call for modifications in their specification documents. These unique changes result in the development of "state blends" as mentioned in Table 3. Colorado has gone through the effort of developing a bead blend for use on epoxy pavement markings and a different blend for use on paint markings. The bead gradations from state specifications are shown in
Table 4. Texas is not represented in
Table 4 because it uses standard gradation requirements, but with a maximum of 2 percent material collected in the pan when tested in accordance with ASTM D 7681 (*TXDOT DMS-8290,* 2013).

Table 4. State DOT Survey Data on State Glass Bead Gradation per Pavement Marking Specifications

U.S. Mesh	Microns	% Passing			
		Colorado		New Mexico	Utah
		Epoxy/MMA	Paint		
16	1180	90-100	100		
18	1000	65-80	97-100	85-95	65-80
20	850		85-100		
30	600	30-50	50-70	65-80	30-50
40	425		10-35		
50	300	0-5	0-10	25-45	0-5
80	180		0-5		
100	150			0-5	

Colorado added that 50 percent of beads by weight for epoxy markings and 15 percent of beads for paint must be manufactured using a molten kiln direct melt method. These beads are expected to be retained above the #30 sieve (mesh). New Mexico specifies the full use of recycled glass from North America.

Colorado, New Mexico, and Utah use the same bead specifications for color/clarity, refractive index, and chemical resistance. Bead roundness requirements vary from 70 percent to 85 percent true spheres. Colorado specifies using optimum bead coating as determined by the marking manufacturer. Adhesion coatings are used by Utah and Texas (Type 3 bead only), and New Mexico specifies a moisture resistant coating. Hazardous materials (arsenic, antimony, and lead) are more tightly restricted by Colorado than the other states, and only Utah uses hardness and crushing strength limits in its bead specifications.

Survey Question 6 focuses on the method of recessing markings. Only Texas responded that it does not practice this. The remaining states' answers are summarized below.

Colorado

- Grooving is used everywhere for epoxy, tape, or preformed thermoplastic to protect from plowing and traffic wear.
    - Epoxy = 40 mil depth at \$0.50-\$0.60/ft^2
    - Tape = 130 mil depth and cost is included in bid price
    - Thermoplastic = 125 mil depth at \$0.50/ft^2
- Recessed markings provide longer service life.

New Mexico

- Grooving is used on Interstates and depth depends on marking material thickness.
- Grooving reduces snow plow damage, but is very expensive.

Utah

- Grooving is used for tape at a groove depth of 125 mils or as recommended by the manufacturer. The groove cost is \$0.40/lf for a 5" wide line.
- Tape markings last longer when recessed in a groove.

Survey Questions 7 and 8 inquire about quality control for installation practices and equipment. None of the survey responses provided specific details on equipment application requirements. Submitted answers are provided below.

Colorado

- "Follow our specifications and standards. Epoxy has a minimum retroreflectivity value."

New Mexico

- "See specifications."

Texas

- "Contractors must supply mobile retroreflectivity data. TxDOT uses a third-party contract to conduct owner verification of the contractor data."

Utah

- "For waterborne paint [Utah] is starting to implement an optional retro measurement protocol for bead acceptance and it's worked well so far. Durable markings are subject to the manufacturer's control."

Climate and Environmental Factors

Pavement marking performance depends on a number of external factors such as pavement surface type, traffic volume, and climate (particularly snowfall regions with snow removal). Survey Question 9 aimed to gather inputs on material type selection based on these factors. According to the survey responses, only Utah uses an official material selection guide.

A link to the UDOT *Pavement Marking Decision Matrix* is provided in the References section. The first table in the UDOT guide is dated 2013 and includes the following attributes for material selection:

- Pavement surface type (concrete, microsurface, open-graded surface course, stone matrix asphalt, bonded wearing course, and chipseal)
- Time to next pavement surface treatment
- Annual Average Daily Traffic (AADT)

This table also includes recommendations for grooving the pavement surface in order to recess the pavement markings. A note on the document states, "In general, grooving will double pavement marking life." The recommendation to groove the pavement is applied to all pavement surfaces that will not require a surface treatment for over five years and at all AADT levels. A second table in the document is titled "Pavement Marking Material Information" and lists estimated cost, length of service life, application temperature requirements, expected initial retroreflectivity, and descriptions of advantages and disadvantages for each material type. The data in this table were last updated in 2010, so some values may already be out of date. Neither table includes guidelines on climate, but the Utah respondent stated in other survey answers that expected service life of recessed tape markings decreases from six to four years at higher elevations.

The NMDOT website contains the "Design Manual: Section 910, Signing and Pavement Markings" (2016), which includes recommendations for pavement marking materials based on traffic volume, pavement type, and pavement remaining service life. These recommendations are shown in Figure 1.

Exhibit 910-7

Recommended Pavement Marking Materials for Bituminous Pavements

	Pavement Remaining Service Life		
Traffic Characteristics	**0 – 2 years**	**2 – 4 years**	**4 years**
ADT* < 1,000	Thermo, WB Paint	Thermo, WB Paint	Thermo, WB Paint, Epoxy, Polyurea, MMA
1,000 < ADT < 10,000	Thermo, WB Paint	Thermo, Epoxy, Polyurea, MMA	Thermo, Tape, Epoxy, Polyurea, MMA
ADT > 10,000	Thermo, Epoxy	Thermo, Tape, Epoxy, Polyurea, MMA	Tape, Thermo, Epoxy, Polyurea, MMA
Heavy Weaving or Turning	Thermo, Epoxy	Thermo, Epoxy, Polyurea, MMA	Thermo, Epoxy, Polyurea, MMA

* *Average Daily Traffic (ADT)*

Exhibit 910-8

Recommended Pavement Marking Materials for Portland Cement Pavements

	Pavement Remaining Service Life		
Traffic Characteristics	**0 – 2 years**	**2 – 4 years**	**4 years**
ADT < 10,000	Thermo, Epoxy, WB Paint	Epoxy, Thermo, WB Paint, Polyurea, MMA	Epoxy, Thermo, Polyurea, WB Paint, MMA
10,000 < ADT < 50,000	Thermo, Epoxy, WB Paint, Polyurea	Epoxy, Thermo, Tape, Polyurea, WB Paint, MMA	Epoxy, Thermo, Polyurea, MMA
ADT > 50,000	Epoxy, Thermo	Epoxy, Thermo, Tape, Polyurea, MMA	Tape, Thermo, Polyurea, Epoxy, MMA
Heavy Weaving or Turning	Epoxy, Thermo, Polyurea	Epoxy, Thermo, Tape, Polyurea, MMA	Epoxy, Thermo, Tape, Polyurea, MMA

Figure 1. NMDOT Pavement Marking Material Selection Recommendations
(Source: Exhibits 910-7 and 910-8 in NMDOT Design Manual: Section 910, Signing and Pavement Markings, 2016)

The traffic levels used in the NMDOT recommendations are different for the two pavement types, and an additional category for locations where weaving (changing lanes) or turning is included. These recommendations do not include guidelines on climate. The contact from New Mexico specified that waterborne paint is preferred where winter maintenance is prevalent.

Texas developed a detailed guide on how and where to use different marking materials. The *TxDOT Pavement Marking Handbook* (2004) contains a wealth of information on common marking materials, including how to place them on different pavement types with different traffic levels. An example table from this document is presented in Figure 2.

Table 2-13. Use of Epoxy Pavement Markings1

-	Asphalt			Concrete			Surface Treatments		
-	AADT <1,000	AADT 1,000 –10,000	AADT >10,000	AADT <10,000	AADT 10,000 –50,000	AADT >50,000	AADT <1,000	AADT 1,000 –10,000	AADT >10,000
Use[2]	Y	Y	Y	Y	Y	Y	Y	Y	Y
Thickness	15–25 mils			15–25 mils			15–25 mils		
Surface prep.	Remove old mkgs, clean, & dry			Remove old mkgs, clean, & dry			Remove old mkgs, clean, & dry		
Expected service life	Up to 4 years	Up to 4 years	Up to 3 years	Up to 4 years	Up to 4 years	Up to 3 years	Up to 4 years	Up to 4 years	Up to 3 years
Approx. bid price (per lf)	$0.40			$0.40			$0.40		
Estimated cost per year of service life (per lf)	$0.10	$0.10	$0.13	$0.10	$0.10	$0.13	$0.10	$0.10	$0.13

Footnotes:
1. A wide variety of epoxy materials are currently available, possessing varying degrees of quality. The information in this table is based on the cost and performance of special formulations of epoxy that are designed for high-quality and high-durability pavement markings commonly used by state DOTs nationwide.
2. Y = suitable for use.

Figure 2. TxDOT Epoxy Pavement Marking Material Use
(Source: Table 2-13 in *TxDOT Pavement Marking Handbook*, 2004)

When Colorado was asked whether it considers climate in its marking material selection decisions, the response was "No" because the entire state is considered a snow removal region. However, material-based questions in other sections of the survey reveal that CDOT expects markings at higher elevations to have half the expected service life of markings at lower ones.

Pavement marking color is an important attribute which can be heavily affected by the amount of ultraviolet light exposure. Survey Question 10 asked the states to rate their overall experience with pavement markings' ability to resist color fading in severe ultraviolet light exposure, and Texas responded with an average rating (4 out of 7). New Mexico reported slightly higher (5) and Colorado's response was highest (6). Both Colorado and Utah identified epoxy markings as experiencing color issues. Utah reported that it does not have a color specification. A summary of the other three state color specifications is provided below and in Figure 3 (Yellow Chromaticity Limits) and Figure 4 (White Chromaticity Limits). As shown in Figure 3 and Figure 4, the specific color or hue of a material is reported in Chromaticity Coordinates, "x,y". Hue is the term used for the classification of a color such as a specific red, yellow, blue, etc.

Colorado (*CDOT Standard Specifications: Division 700*)

- Paint color specification is located in section 708.05 and references Federal Standard Number 595B-17925. It sets an initial maximum Yellowness Index at 8.0 per ASTM E313 for white material. Yellow materials should meet the initial daytime chromaticity limits as plotted in Figure 3.
- Epoxy color specification is located in section 713.17. It calls for the same requirements set forth by the paint color specification but includes an additional, two-step testing procedure according to ASTM G154 with maximum Yellowness Index values associated with each test for white

materials. Yellow materials are also required to go through an additional testing procedure according to ASTM G154 and must meet the same chromaticity requirement as paint.

New Mexico (*NMDOT Specifications for Highway and Bridge Construction, 2014)*

- Thermoplastic material color requirements are available in Section 704.2.5.1.1 and require reflectance and color testing on material samples that have gone through a specific heating procedure. Documented standards include comparison to Federal Test Standard Number 595 color chip no. 17925 (white) and no. 13538 (yellow).
    - In addition, white thermoplastic is not to exceed a Yellowness Index of 0.12 when tested in accordance with Section 4 of AASHTO T 250.
    - Accelerated weathering test requirements per ASTM G155 require white color to remain stable through 500 hours of exposure and yellow must be stable through 1,000 hours.

Texas (*TxDOT Departmental Materials Specification 8200 and Special Specification 6038*)

- Thermoplastic materials must meet TxDOT DMS 8220, which includes daytime color requirements for white, yellow, and black material. The chromaticity limits, determined in accordance with Tex-839-B, are shown in Figure 3 and Figure 4.
    - DMS 8220 also includes testing requirements using weathering testing of ASTM G 155, exposure cycle 1. White must sustain color for at least 70 hours and yellow for 1,000 hours.
    - Nighttime color requirements are also set in these specifications.
- Epoxy materials also must meet unique color requirements as prescribed in TxDOT Special Specification 6038. White material chromaticity limits are the same as those for thermoplastic (Figure 4), and yellow chromaticity limits are shown in Figure 3.

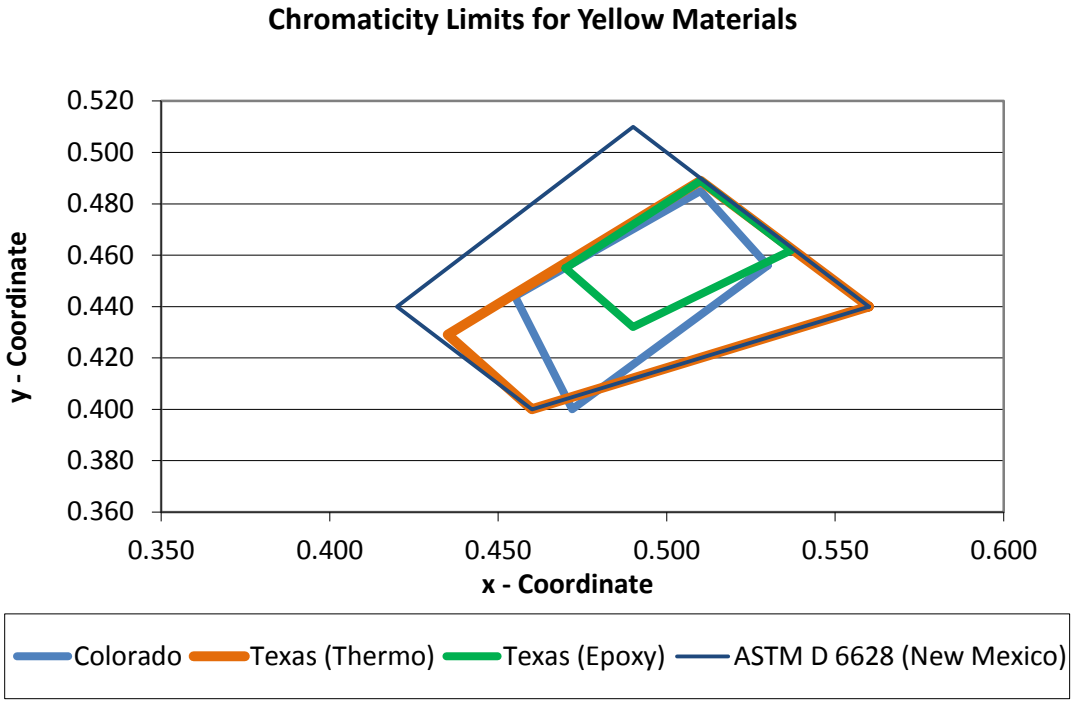

Figure 3. State DOT Pavement Marking Survey Data on Yellow Chromaticity Limits for Initial Daytime Color

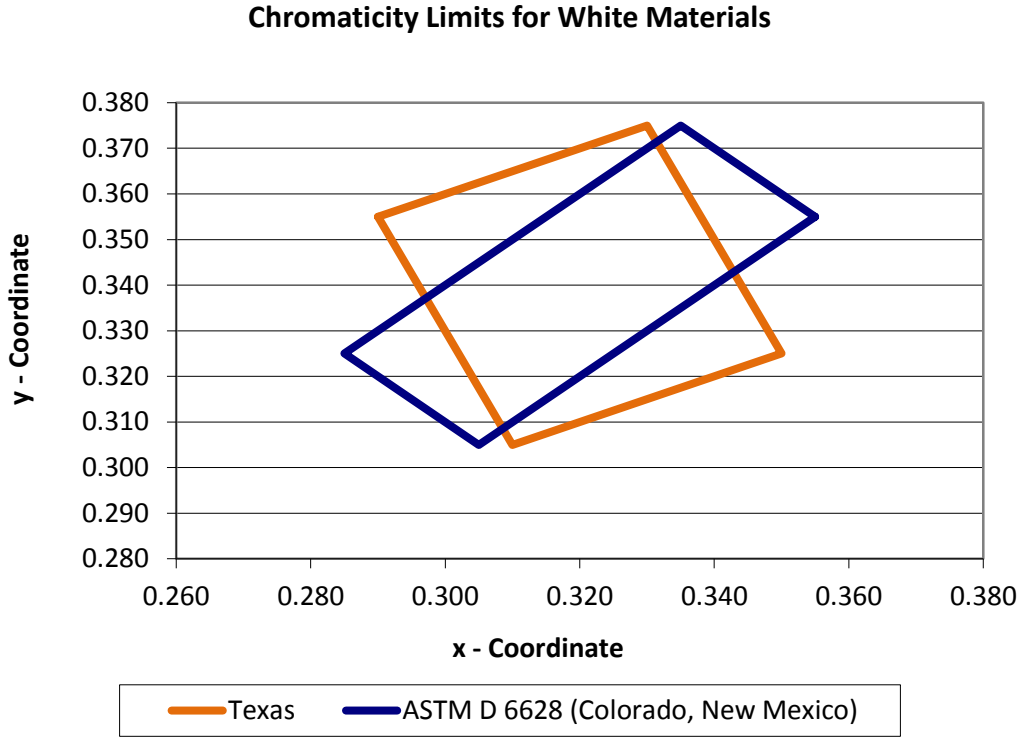

Figure 4. State DOT Pavement Marking Survey Data on White Chromaticity Limits for Initial Daytime Color

Some color specifications referenced in the state manuals represent initial material color without reflective beads, while others apply to part or all of the material's life cycle. Colorado, New Mexico, and Texas include modified procedures for using accelerated weathering tests to ensure that material can withstand exposure to sunlight and moisture. Colorado applies the weathering tests to epoxy, whereas New Mexico and Texas apply them to thermoplastic.

As Figure 3 shows, the different state daytime chromaticity limits for yellow almost always align with or fall inside the limits set in ASTM D 6628, the Standard Specification for Color of Pavement Marking Materials. State limits are always more restrictive by reducing the area within the limits. In particular, Texas's epoxy requirements reduce the acceptable chromaticity area by more than half. Comparison of Texas white chromaticity limits to the ASTM in Figure 4 shows that the Texas-approved chromaticity limits only partially overlaps with the ASTM limits.

Marking Management and Performance-Based Specifications

The responses to the survey's Questions 11 through 15 regarding in-practice marking management strategies and performance-based specifications are summarized as follows:

Colorado

- The only responding state which has a statewide pavement marking management program.
- Uses roadway attribute data, marking installation data, expected end of service life, and performance data for determining annual pavement marking projects. The state is also willing to share performance data with ADOT.
- Uses a minimum retroreflectivity of 80 millicandela (mcd) and/or deteriorated presence as criteria for end of service life.
- Uses minimum initial retroreflectivity value requirements (400 white, 250 yellow), which produces "excellent" results, according to the CDOT contact.
- In addition to the survey response, CDOT provided a 2010 research report about its case studies on the cost-effectiveness of warranties for epoxy pavement marking life. These studies found that warranties are not cost-effective.

New Mexico

- Does not collect pavement marking performance data or use a marking management program.
- The contact omitted details pertaining to criteria for end of service life and strategy for prioritizing maintenance efforts, other than funding limits.
- The contact specified that NMDOT uses a one-year warranty on pavement markings. In addition, the NMDOT *Standard Specifications for Highway and Bridge Construction* requires minimum initial retroreflectivity values for thermoplastic markings.

Texas

- Currently "does not have an objective statewide pavement marking management program, although one may be developed in the near future." – Texas Department of Transportation Pavement Marking Handbook, 2004: Appendix A, Section 5.
- Has traditionally used expected end of service life and nighttime visual inspections to plan maintenance efforts.
- Considers markings to have reached the end of service life when a driver cannot see more than three dash markings in front of the vehicle during a nighttime survey.
- Some Texas districts have begun using measured retroreflectivity data to assist in site prioritization. This data is managed by those districts and is not easily accessible.
- TxDOT's *Special Specification 6038* for epoxy markings sets minimum retroreflectivity and durability requirements.
- The contact specified that TxDOT used to use warranties (on prefabricated tape) but has moved away from the practice. No details were provided as to why that decision was made.

Utah

- Waterborne paint markings are applied on a one-year to two-year schedule and other durable materials are restriped at the end of service life.
- Specifications set a minimum retroreflectivity of 125 mcd as criteria for end of service life. However, a minimum of 150 mcd has been used on selected projects that have very high AADT. Specifications also define a minimum presence level as 90 percent of a longitudinal line on any 1,000-foot segment. (*UDOT Standard Specifications For Road and Bridge Construction*, 2017: Section 02768)
- Utah maintains marking installation data but does not collect performance data. The state uses performance-based specifications, which require marking manufacturers and suppliers to meet defined minimum service life based on material type as well as minimum performance measures for retroreflectivity and presence.
- Utah uses a warranty specification but did not comment further on its effectiveness.

Each state's management strategy is different, ranging from Colorado's statewide pavement marking management database to Utah's plan to have marking manufacturers monitor marking performance. Three out of four are using retroreflectivity data to assess either initial performance or life cycle performance of markings to increase the effectiveness of their pavement marking network. Warranties didn't work for Colorado or Texas, and Utah didn't comment on warranty effectiveness.

Summary

The state DOTs participating in this survey are facing similar challenges to ADOT in pavement marking management. The methods they have used to increase material performance are listed below. The states using these methods are listed in parentheses.

- Developing glass bead gradations to optimize performance for specific materials through field testing (Colorado, New Mexico, Utah).
- Recessing marking material in a groove found to extend marking service life (Colorado, New Mexico, Utah).
- Using thicker wet film thicknesses of paint and thermoplastic markings can increase marking performance (Texas).
- Requiring pavement marking products to provide proof of performance through NTPEP test results or local field evaluation testing (Colorado, Texas).
- Using minimum initial retroreflectivity and/or initial durability specifications for durable markings sets a performance goal for material suppliers (New Mexico, Texas). A higher initial performance does not guarantee better life-cycle performance, but the testing will identify some instances of poor installation practices.
- Adding accelerated weathering test requirements or tighter daytime chromaticity requirements to material specifications, primarily for epoxy, promotes better color performance (Colorado, New Mexico, Texas).
- Defining a minimum retroreflectivity for end of service life helps ensure roadways are restriped as needed (Colorado, Utah).

NTPEP DATAMINE RESULTS

The list of materials placed on the Minnesota (2010), Pennsylvania (2011), and Florida (2012) NTPEP test decks was filtered to remove materials designed for letters and symbols (preformed thermoplastic), non-durable materials (paint and temporary), and a high-cost durable material (preformed tape). The remaining materials for analysis included epoxy, polyurea, thermoplastic, urethane, and methyl methacrylate (MMA). Three performance metrics (dry retroreflectivity, durability, and daytime color) were analyzed, and results are summarized in the following sections. Both retroreflectivity and durability readings were taken on two locations of each transverse sample. An 18-inch section of marking centered on the left wheel path area is reported as “wheel” in the database and the nine inches closest to the skip line area is reported as “skip.” Only data from the skip location was analyzed since it best represents the location and wear of regular, in-service pavement markings. To simplify the presentation of the results, the final set of data (data collected at the end of the 36-month evaluation period) for all three metrics were assigned a rating of “Good,” “Fair,” or “Poor.” The threshold values of the ratings for each performance metric are described in the following sections.

Data from a total of 69 products were extracted from NTPEP’s DataMine. In the tables and charts in the following evaluations, the marking materials are identified by their NTPEP Code, the state test deck, and

color. Appendix C provides a list of the product names. Information about the reflective glass beads used for each product, such as bead type, bead application rate, bead coating, and intermix percent, is provided in Appendix D.

Dry Retroreflectivity

NTPEP dry retroreflectivity readings are collected with a 30-meter geometry portable retroreflectometer in accordance with American Society for Testing and Material (ASTM) D 1710. The readings were taken in the wheel path and in the skip location of each marking. In both cases the retroreflectometer was oriented to face the direction of application when taking the reading (*NTPEP Committee Work Plan for Field Evaluation Of Pavement Marking Materials)*.

Retroreflectivity is the most common metric for measuring the performance of pavement markings. It is a measure of how much of a projected light (light from a vehicle's headlamps) upon a pavement marking is reflected back to the driver's eyes. Initial values vary depending on the type of material and reflective media (e.g., glass beads) used, but are typically between 200 and 1,000 mcd/m^2/lux. Plots of material retroreflectivity performance (degradation over time) grouped by material type and pavement type are provided in Figures 5 through 26 and are described below.

Epoxy markings were on the Minnesota and Pennsylvania test decks. Retroreflectivity performance on the asphalt and the concrete surfaced roadways are shown in Figure 5 and Figure 6, respectively, and summarized here:

- Products 046 and 047 started out with higher retroreflectivity values due to their special optics, called clusterbeads, but both dropped to values similar to traditional glass beads in less than 12 months. A clusterbead is a single bead coated with many smaller beads.
- Yellow materials consistently had lower retroreflectivity values than their white counterparts.
- All markings ended the research period with values above 100 mcd, and many were above 150 mcd. With fairly slow rates of deterioration, most of these materials could be expected to continue providing adequate visibility for additional years.

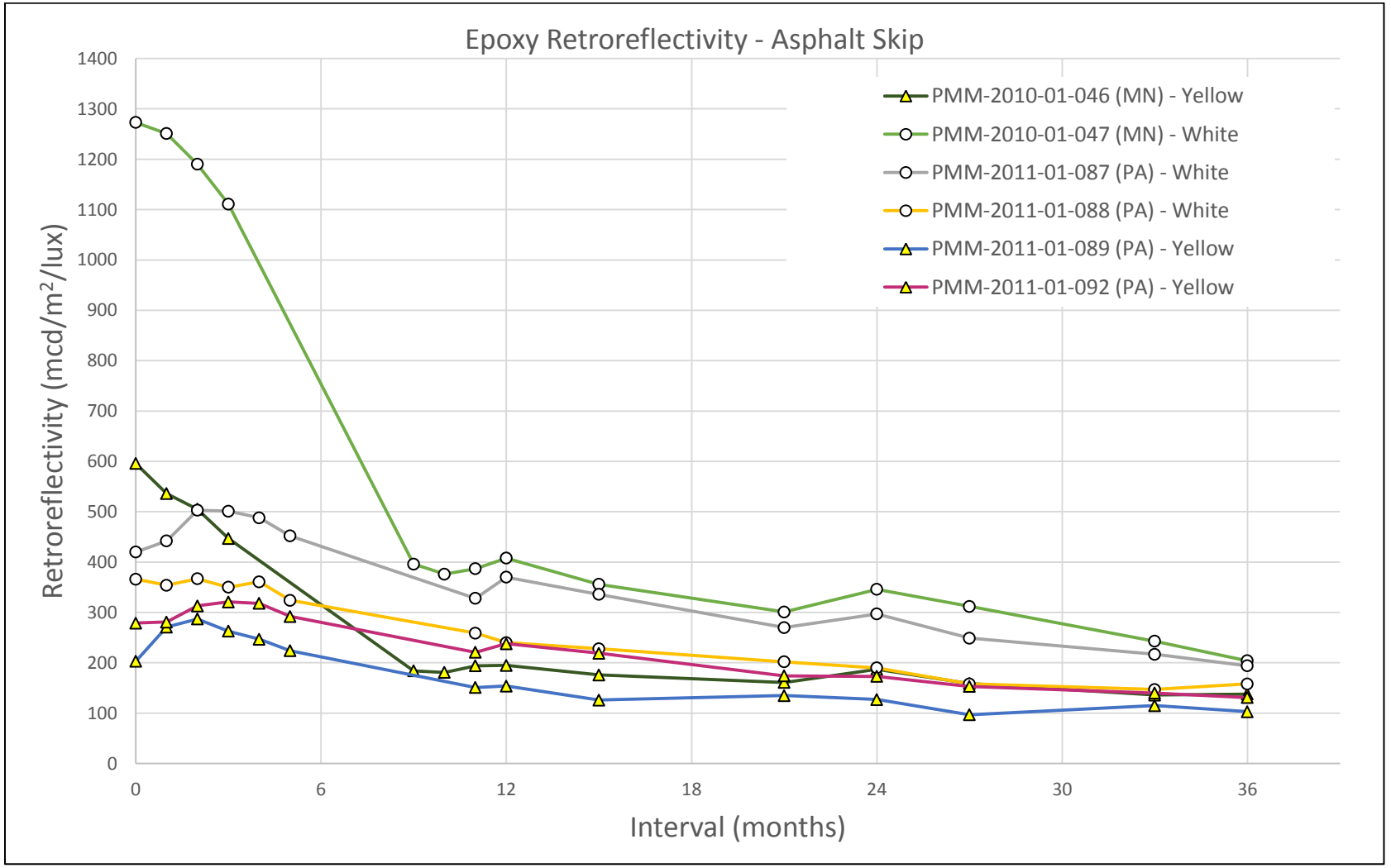

Figure 5. Retroreflectivity of Epoxy Materials on Asphalt (Skip Location) on Minnesota and Pennsylvania Test Decks
(Source: NTPEP Datamine)

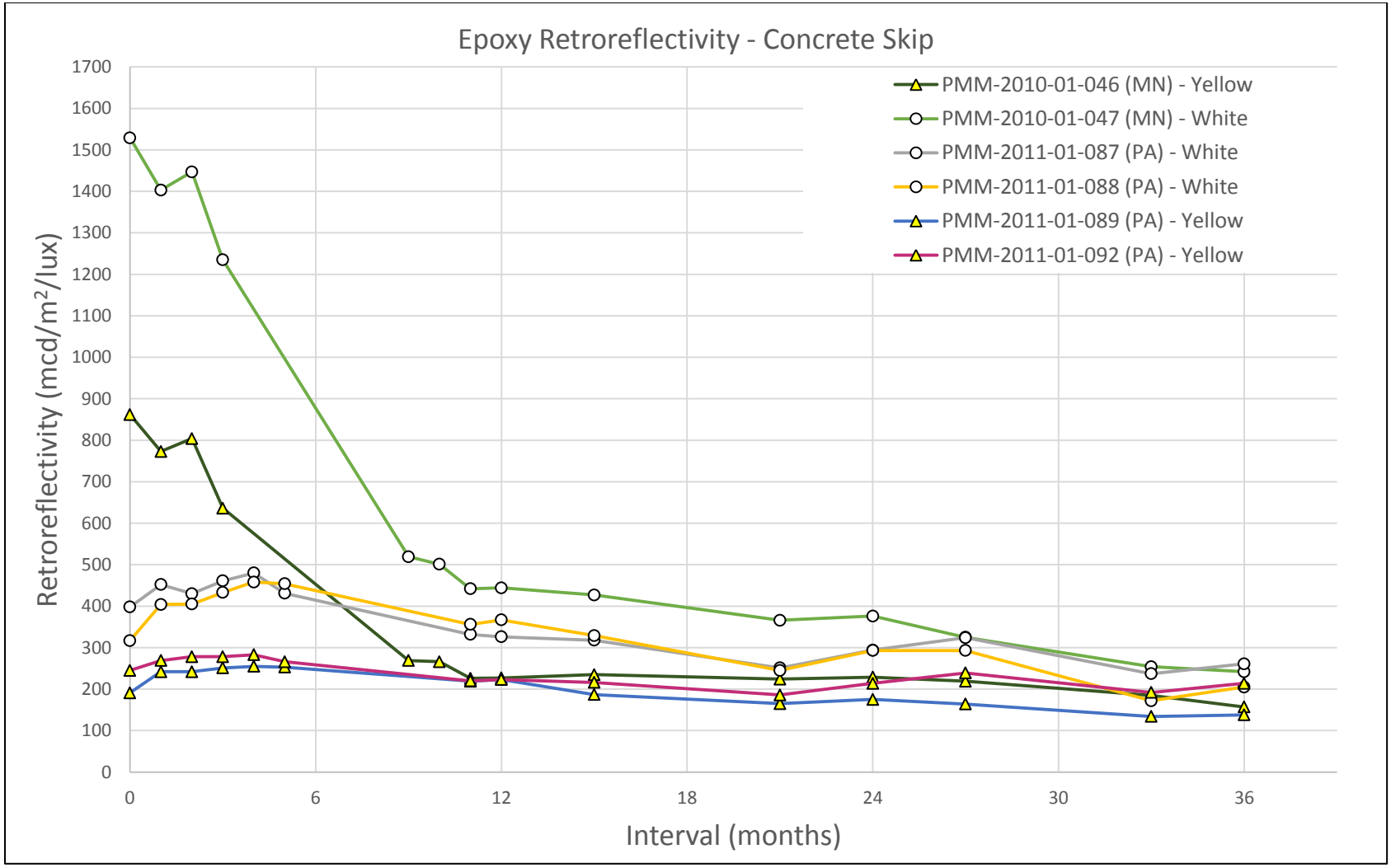

Figure 6. Retroreflectivity of Epoxy Materials on Concrete (Skip Location) on Minnesota and Pennsylvania Test Decks
(Source: NTPEP Datamine)

Polyurea markings were on the Minnesota and Florida test decks. Retroreflectivity performance on the asphalt and the concrete surfaced roadways are shown in Figure 7 and Figure 8, respectively, and summarized here:

- The materials in Florida had very high initial values on both pavement types and maintained fairly consistent rates of deterioration. The higher initial retroreflectivity is likely due to the special "Utah Bead Blend" used on them, and maintaining a higher value longer than the Minnesota markings is possibly a result of not having snow removal.
- The Minnesota markings, Products 058 through 061, used an AASHTO Type 1 and Type 3 bead.
- Yellow materials consistently had lower retroreflectivity values than the same white materials.
- Yellow materials in Minnesota had low initial retroreflectivity on both pavement types and quickly dropped below 100 mcd.
- There is a large spike in the Florida polyurea data on concrete which is not typical of any marking material. This spike is also present in the Florida thermoplastic data on concrete pavements at the same location and time. Therefore, it is likely that the spikes were caused by a variance in the equipment or conditions specific to that round of data collection.

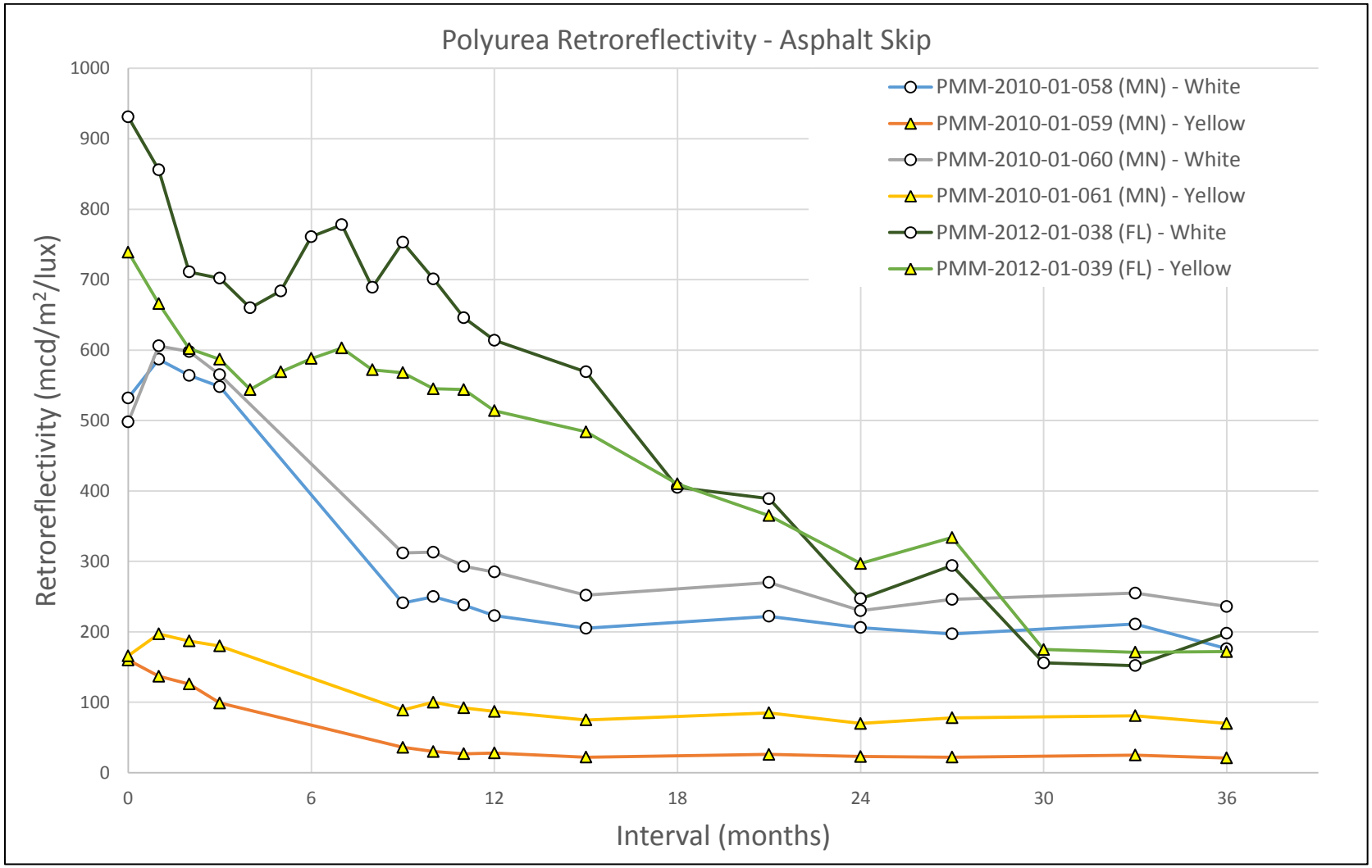

Figure 7. Retroreflectivity of Polyurea Materials on Asphalt (Skip Location) on Florid and Minnesota Test Decks
(Source: NTPEP Datamine)

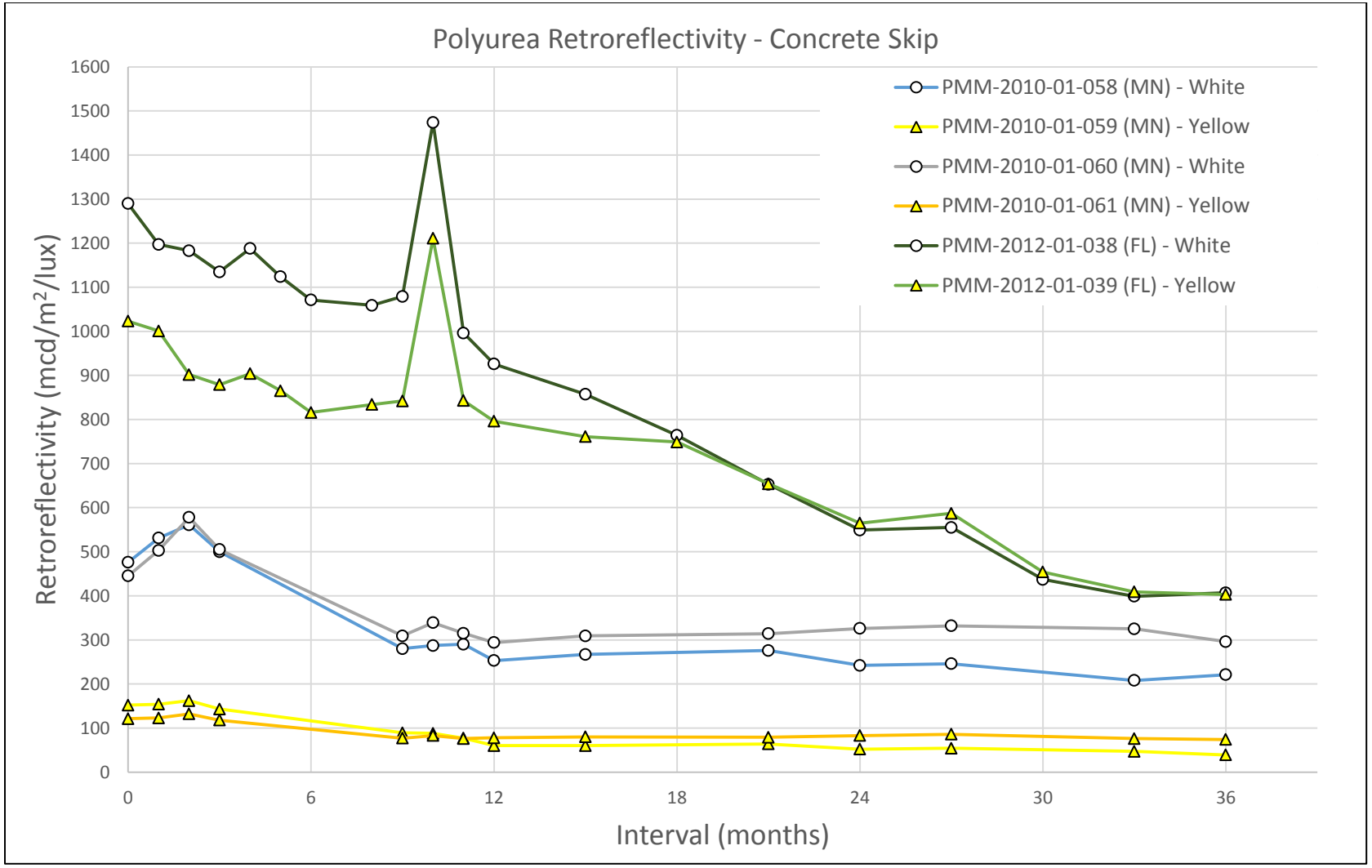

Figure 8. Retroreflectivity of Polyurea Materials on Concrete (Skip Location) on Florida and Minnesota Test Decks
(Source: NTPEP Datamine)

Thermoplastic markings were on the test decks in all three states, and all thermoplastic markings had intermix beads, with 30 percent to 40 percent of bead product as intermix. Due to the large number of thermoplastic markings being evaluated, the data from the two northern states, Minnesota and Pennsylvania, is presented separately to more easily view the data. The white and yellow markings are also presented on separate graphs. The retroreflectivity performance of the Minnesota and Pennsylvania thermoplastic markings on the asphalt and the concrete surfaced roadways are shown in Figure 9 through

Figure 12 and summarized here:

- Yellow materials on both pavement types had lower retroreflectivity values than white materials over the course of the research periods, and all dropped below 100 mcd before 36 months.
- With the exception of the single white thermoplastic on concrete in Minnesota, all white materials performed well, with retroreflectivity values still over 100 mcd.
- The intermix beads are likely why the markings maintained retroreflectivity values fairly well after the first winter and the source of the slight increase after the second winter.

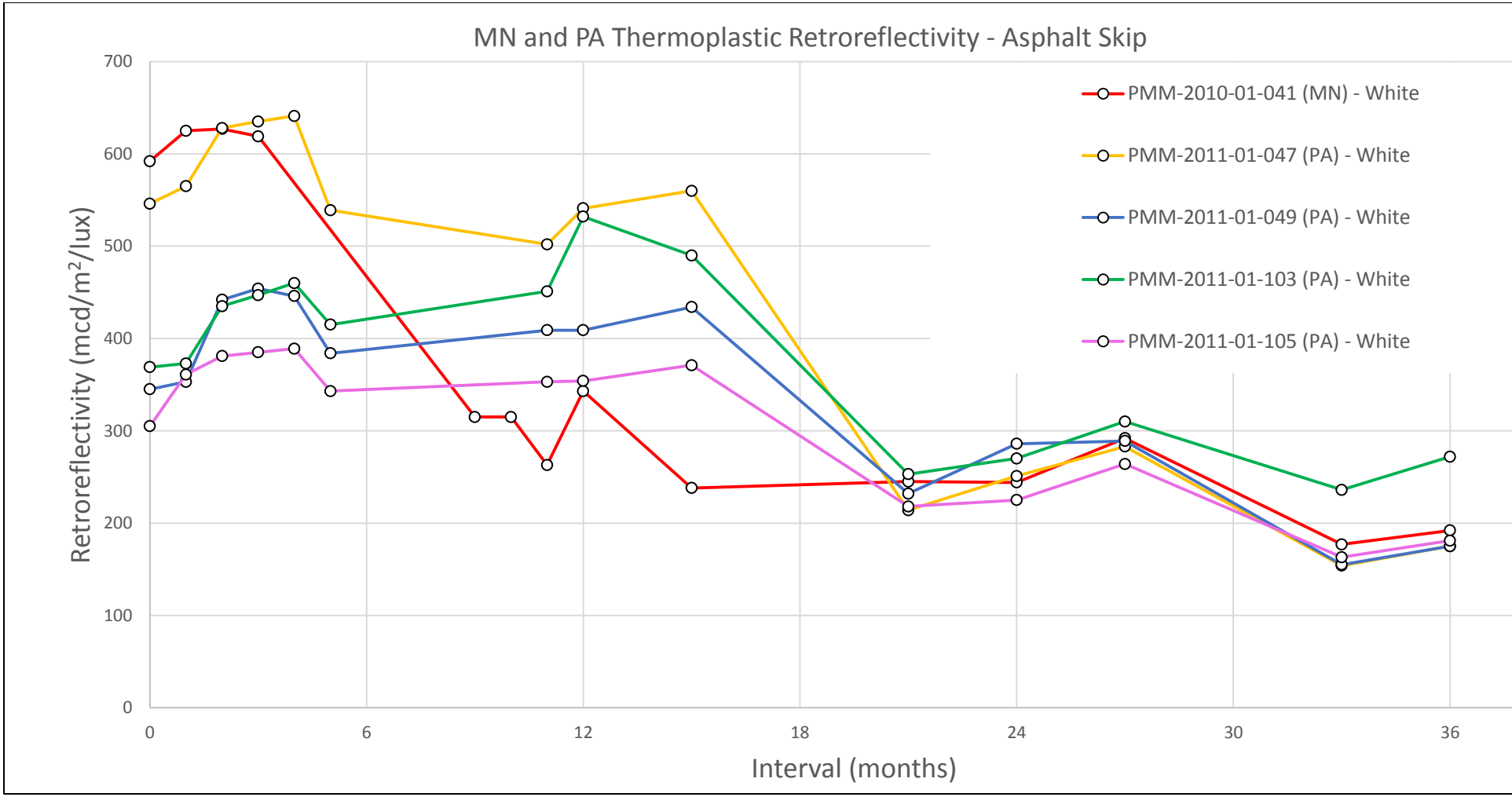

Figure 9. Retroreflectivity of White Thermoplastic Materials on Asphalt on Minnesota and Pennsylvania Test Decks (Skip Location)
(Source: NTPEP Datamine)

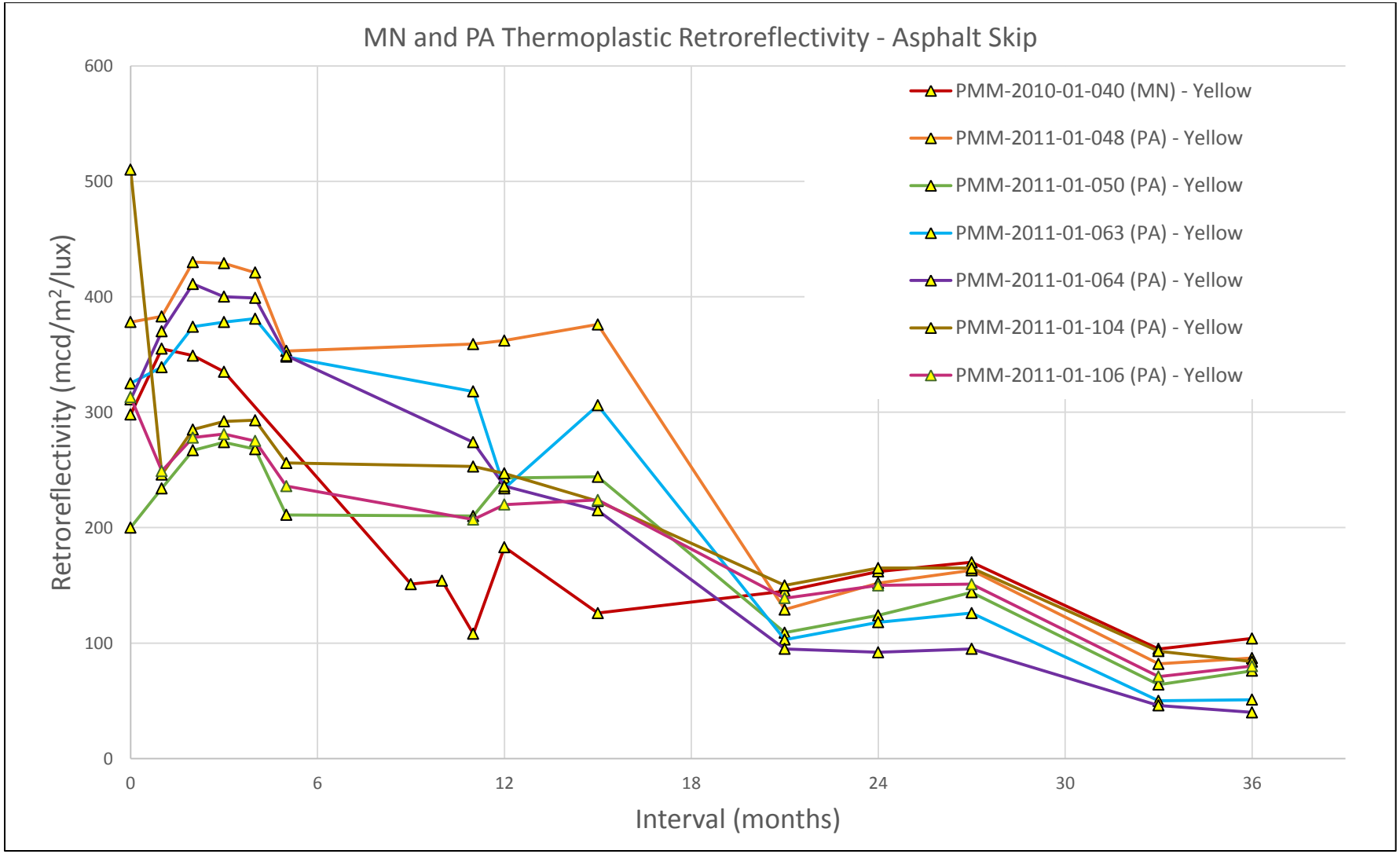

Figure 10. Retroreflectivity of Yellow Thermoplastic Materials on Asphalt on Minnesota and Pennsylvania Test Decks (Skip Location)
(Source: NTPEP Datamine)

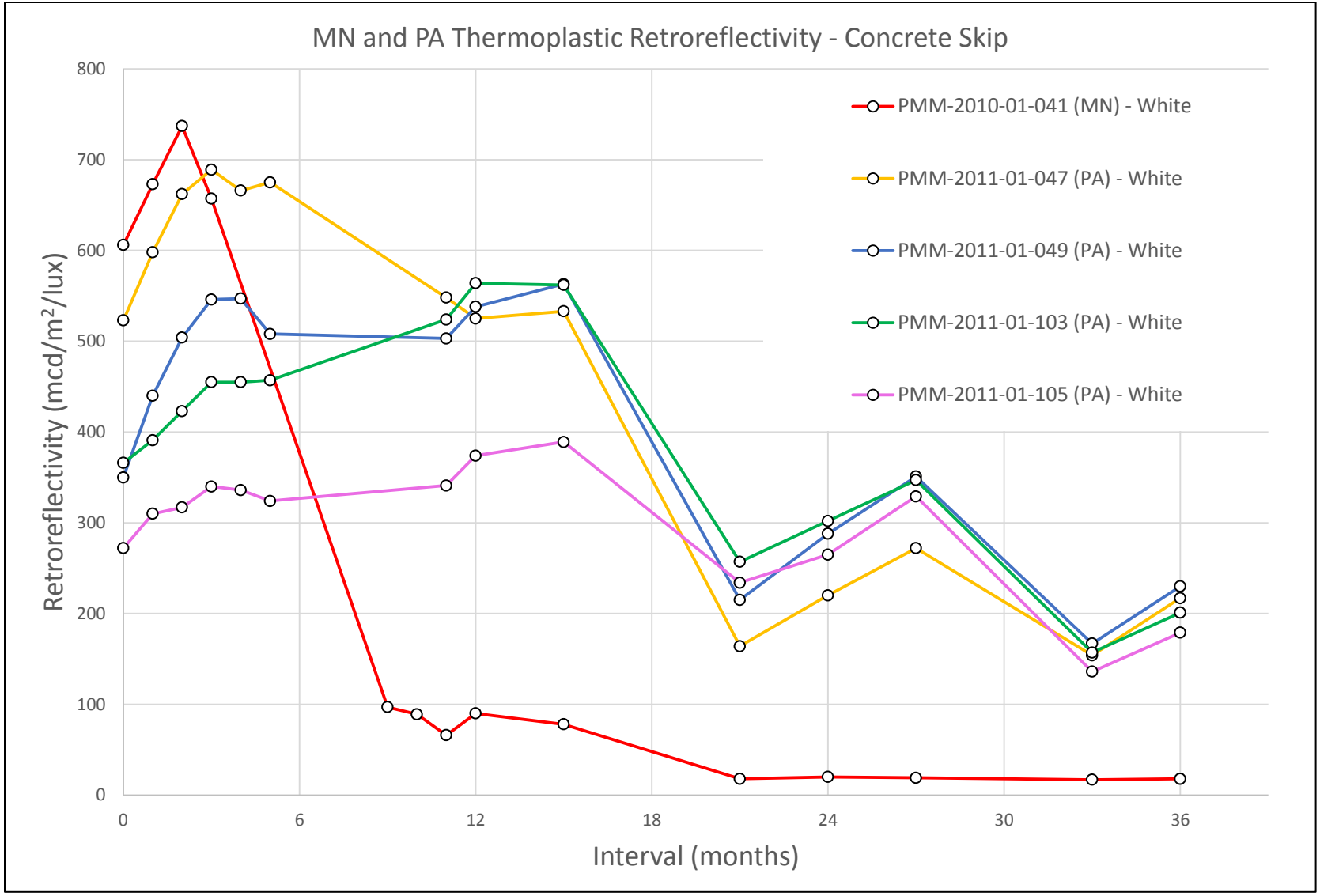

Figure 11. Retroreflectivity of White Thermoplastic Materials on Concrete on Minnesota and Pennsylvania Test Decks (Skip Location)
(Source: NTPEP Datamine)

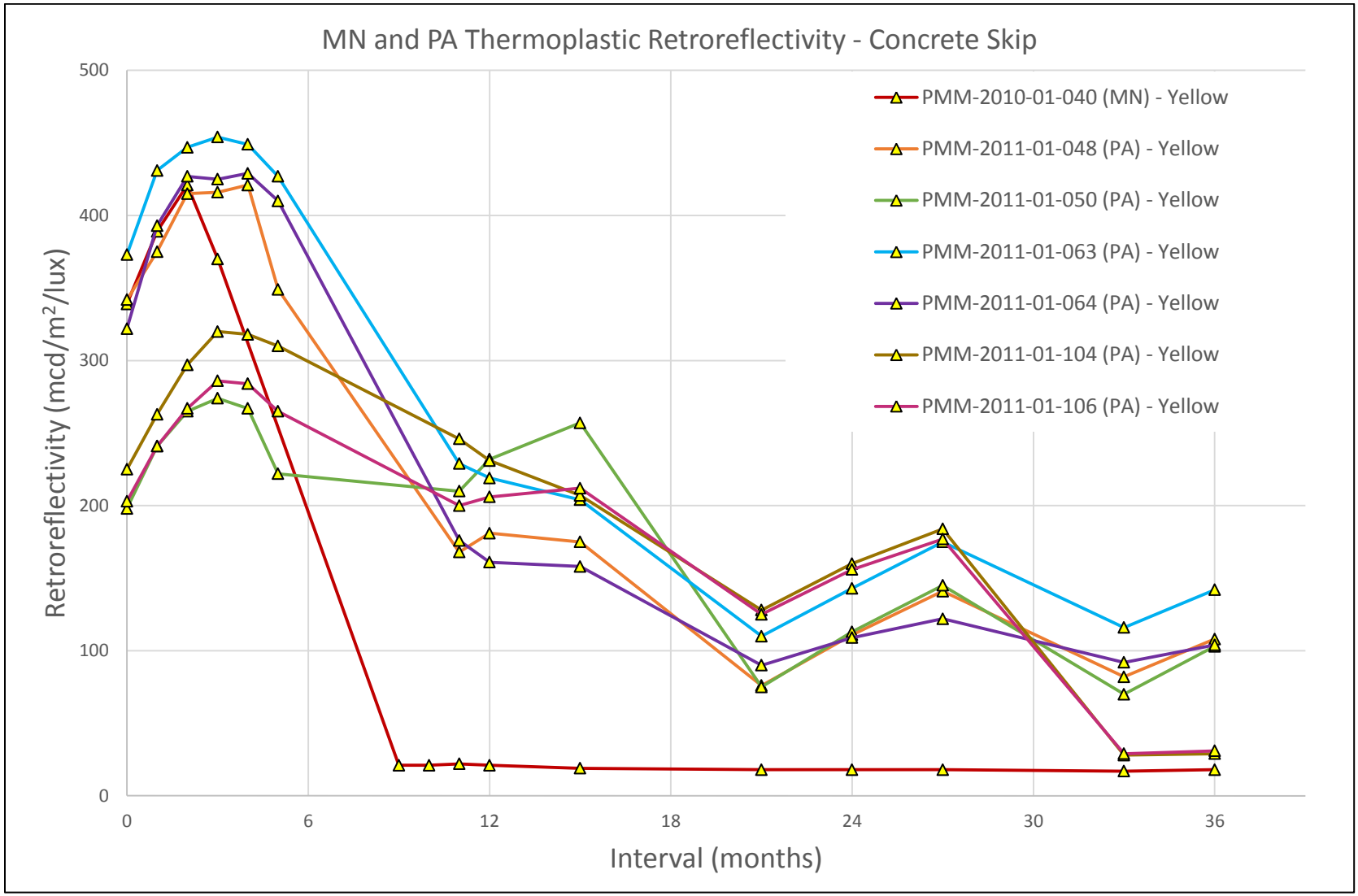

Figure 12. Retroreflectivity of Yellow Thermoplastic Materials on Concrete on Minnesota and Pennsylvania Test Decks (Skip Location)
(Source: NTPEP Datamine)

The retroreflectivity performance of the white and yellow thermoplastic markings in Florida on the asphalt and the concrete surfaced roadways are shown in Figure 13 through Figure 16 and are summarized here:

- The trend of yellow materials having lower retroreflectivity values than white materials continued in the Florida thermoplastic data.
- Extended periods of high retroreflectivity in the Florida data show how intermix beads and no snow removal can allow thermoplastics to have a longer service life than colder climates. Three materials on asphalt and one on concrete had retroreflectivity values over 500 mcd at 36 months.
- No factor, such as glass bead type or higher/lower intermix bead percent, was identified as the reason why some markings had higher retroreflectivity values than others.

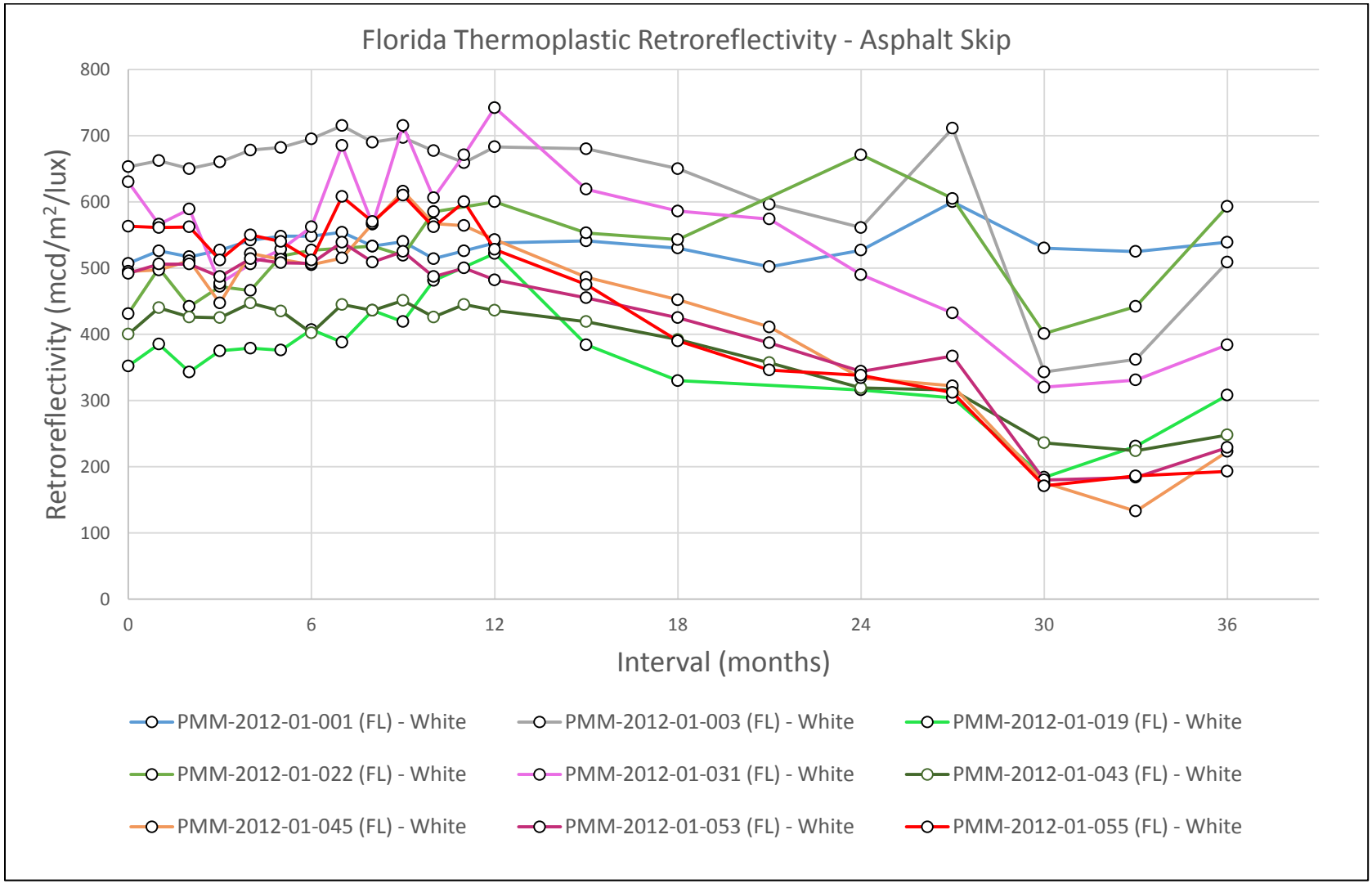

Figure 13. Retroreflectivity of White Thermoplastic Materials on Asphalt on Florida Test Deck (Skip Location)
(Source: NTPEP Datamine)

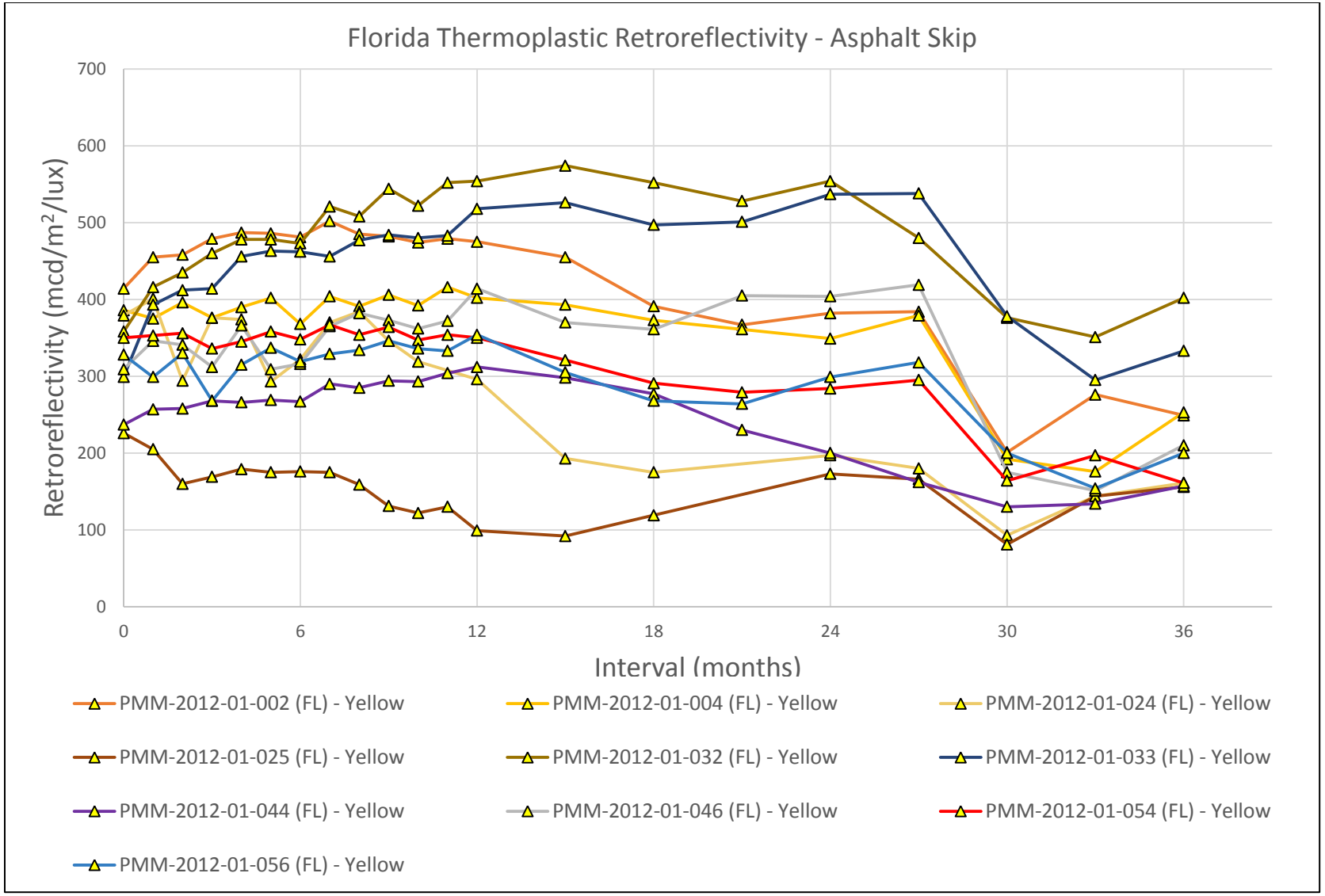

Figure 14. Retroreflectivity of Yellow Thermoplastic Materials on Asphalt on Florida Test Deck (Skip Location)
(Source: NTPEP Datamine)

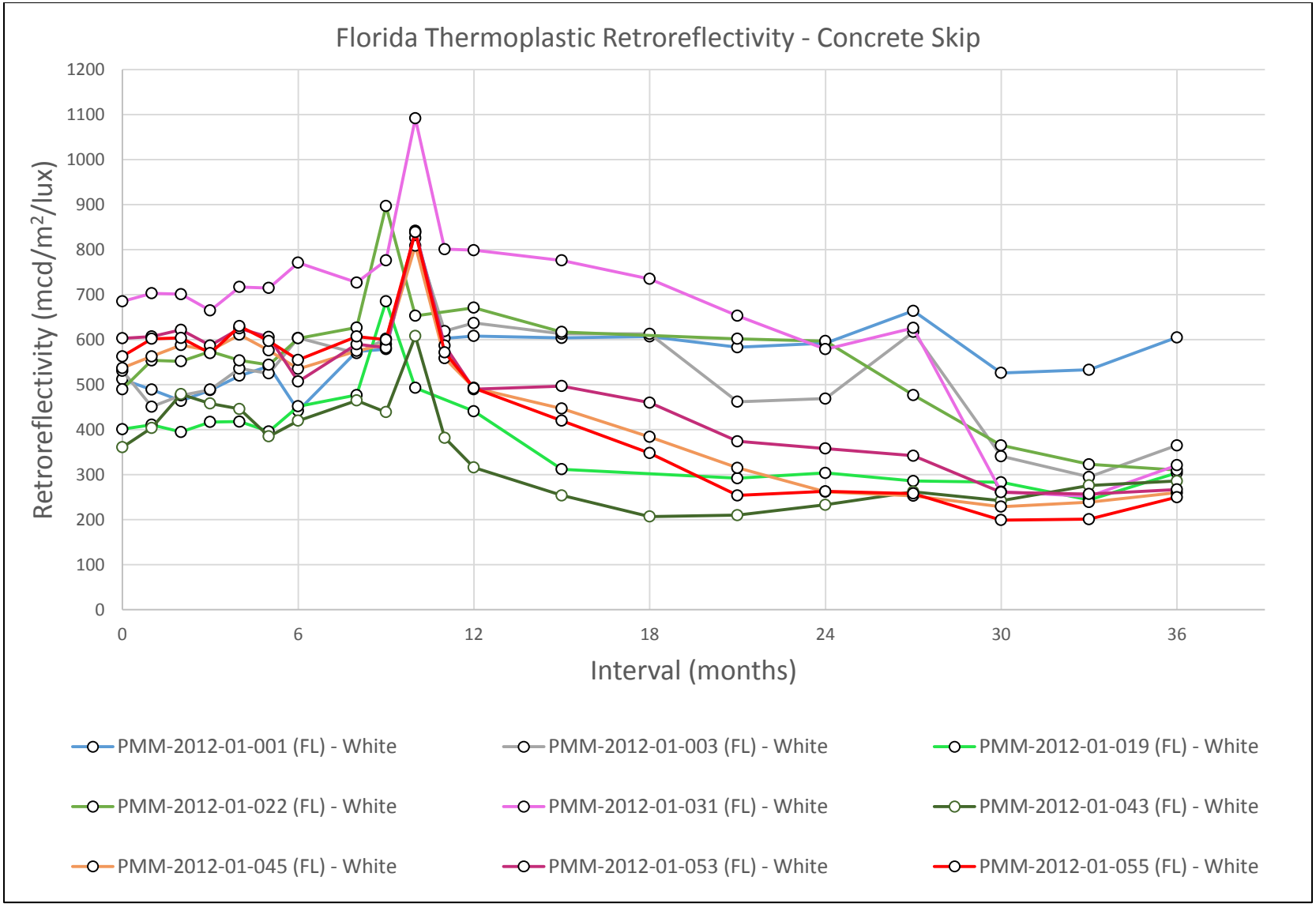

Figure 15. Retroreflectivity of White Thermoplastic Materials on Concrete on Florida Test Deck(Skip Location)
(Source: NTPEP Datamine)

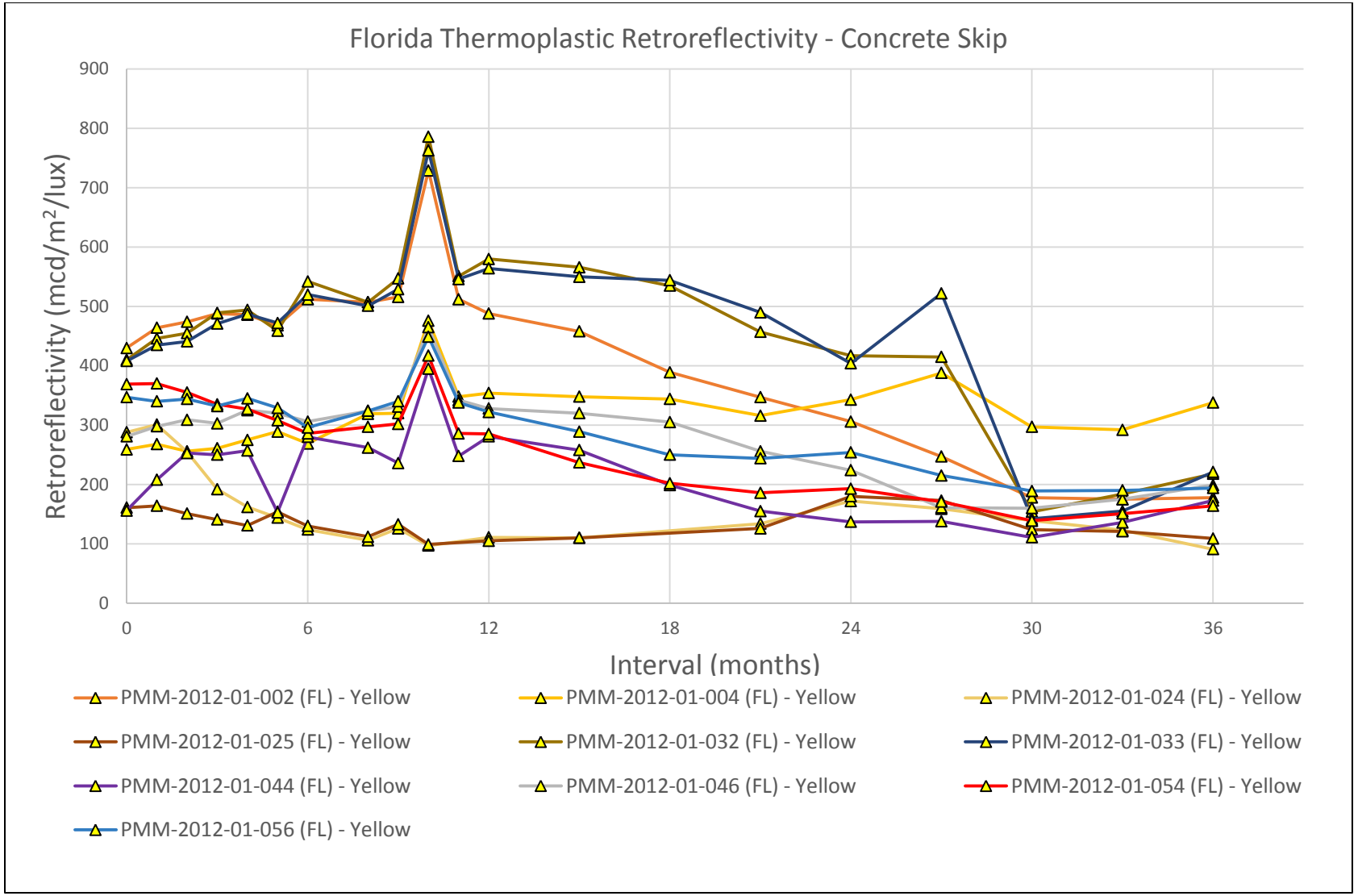

Figure 16. Retroreflectivity of Yellow Thermoplastic Materials on Concrete on Florida Test Deck (Skip Location)
(Source: NTPEP Datamine)

Urethane markings were on the Minnesota and Pennsylvania test decks. Retroreflectivity performance on the asphalt and the concrete surfaced roadways are shown in Figure 17 and Figure 18, respectively, and are summarized here:

- Like other marking materials, the urethane yellow markings have lower retroreflectivity values than their white counterparts.
- All markings experienced fairly rapid deterioration after the first winter and then maintained retroreflectivity values at or above 100 mcd for the next two years.
- Products 044 and 045 started out with higher retroreflectivity values due to their special optics, called clusterbeads.

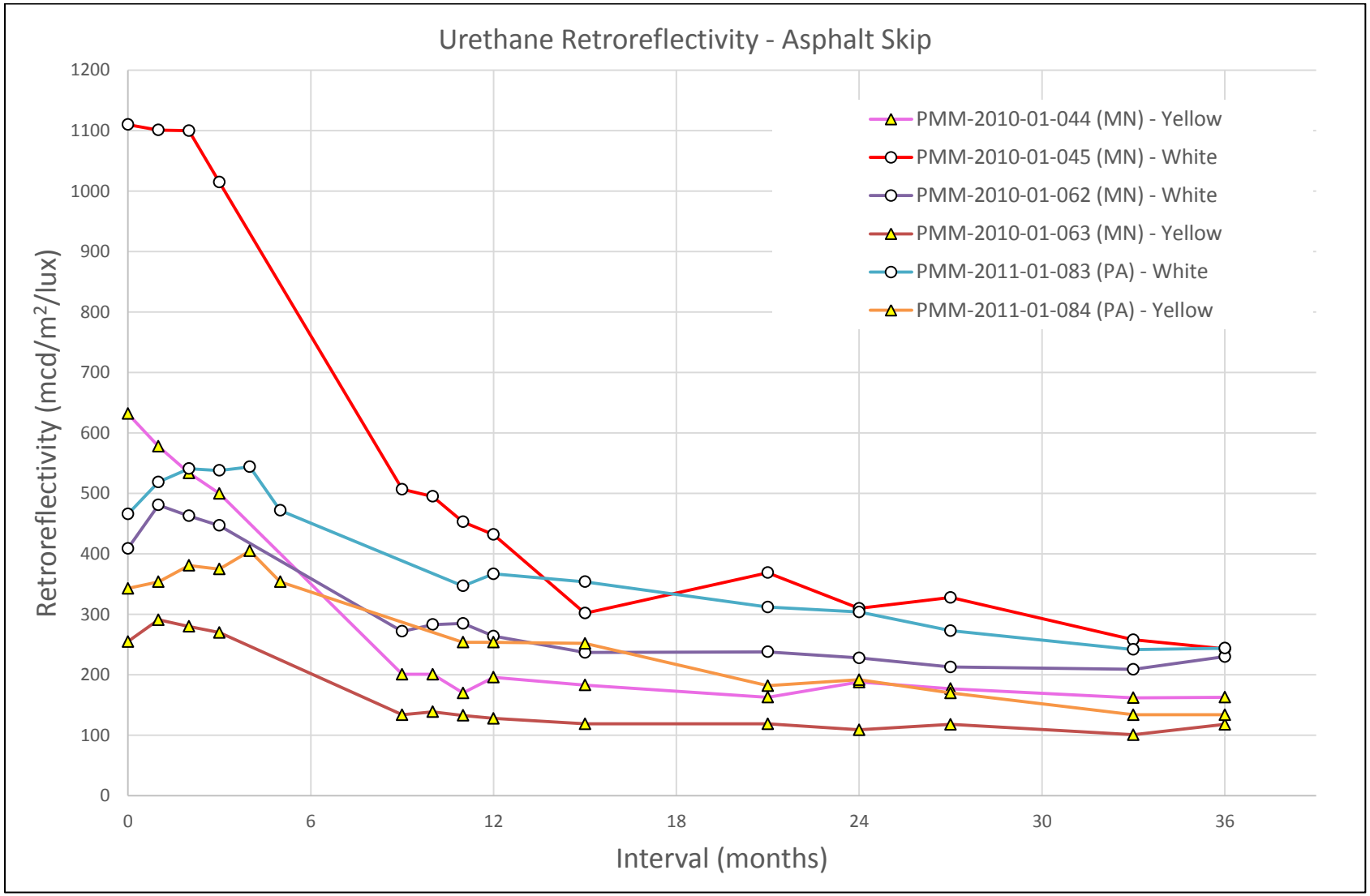

Figure 17. Retroreflectivity of Urethane Materials on Asphalt on Minnesota and Pennsylvania Test Decks (Skip Location)
(Source: NTPEP Datamine)

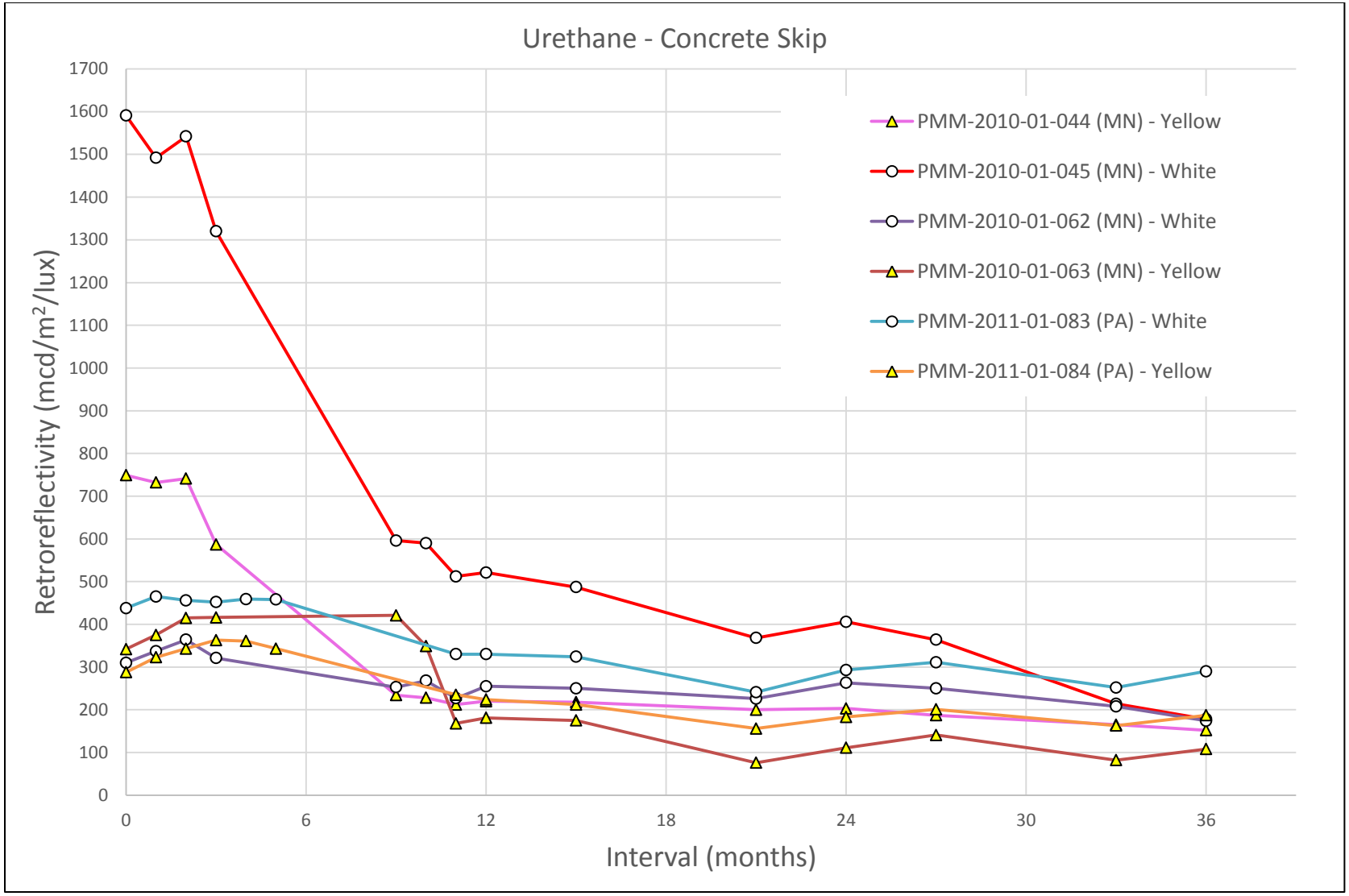

Figure 18. Retroreflectivity of Urethane Materials on Concrete on Minnesota and Pennsylvania Test Decks (Skip Location)
(Source: NTPEP Datamine)

MMA markings were on the test decks in all three states, and due to the large number of MMA markings the data is presented separately for each state to make it easier to view. The retroreflectivity performance of the Minnesota MMA markings on the asphalt and the concrete surfaced roadways are shown in

Figure 19 and
Figure 20, respectively, and are summarized here:

- Like other marking materials, the MMA yellow markings have lower retroreflectivity values than their white counterparts.
- Product 043 used a single drop of an uncoated Type 1 bead at an application rate of 16 lbs/gallon. Product 006 used a single drop of an adhesion coated Type 5 bead at an application rate of 12 lbs/gallon. Product 008 used a single drop of an adhesion coated Type 1 bead at an application rate of 10 lbs/gallon. The higher retroreflectivity values appear to be related to the larger volume of beads (higher application rates); however, initial retroreflectivity values as high as those of Product 043 and 006 are usually due to special reflective media, not traditional glass beads. The three companion yellow products (Product 007, 009, and 042) had the same beads and application rates, except Product 009 used a Type 5 bead, and none of the yellow products had comparable high initial retroreflectivity values, except Product 042 on concrete. There's no known reason the different pavement surface type would cause the Product 042 on concrete to by higher than the same placement on asphalt. The difference is likely due to a difference that occurred at the time of installation.
- The MMA markings appear to have performed slightly better on the asphalt pavement since after three years more of the markings on concrete had fallen below 100 mcd.

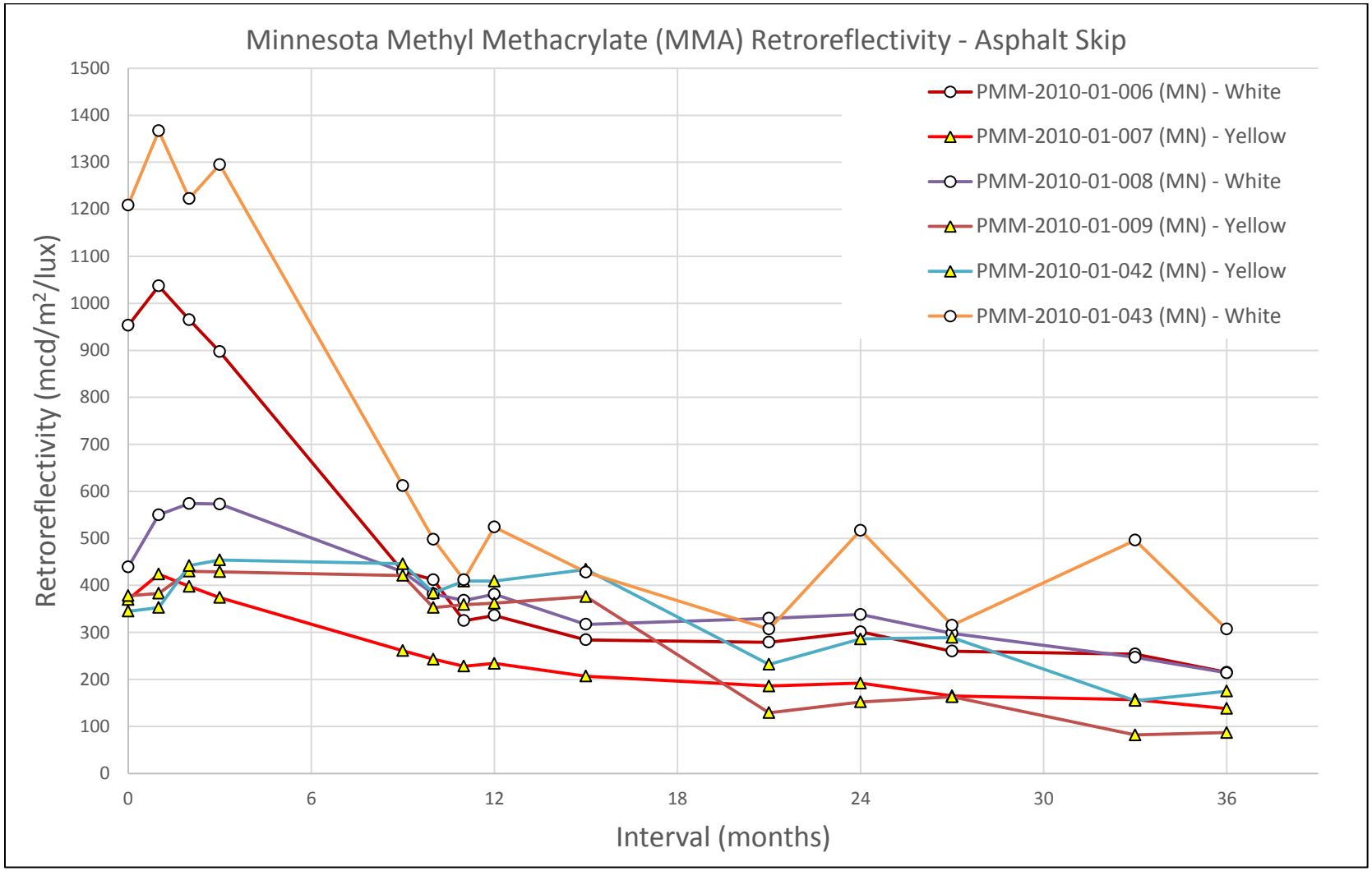

Figure 19. Retroreflectivity of MMA Materials on Asphalt on Minnesota Test Deck (Skip Location)
(Source: NTPEP Datamine)

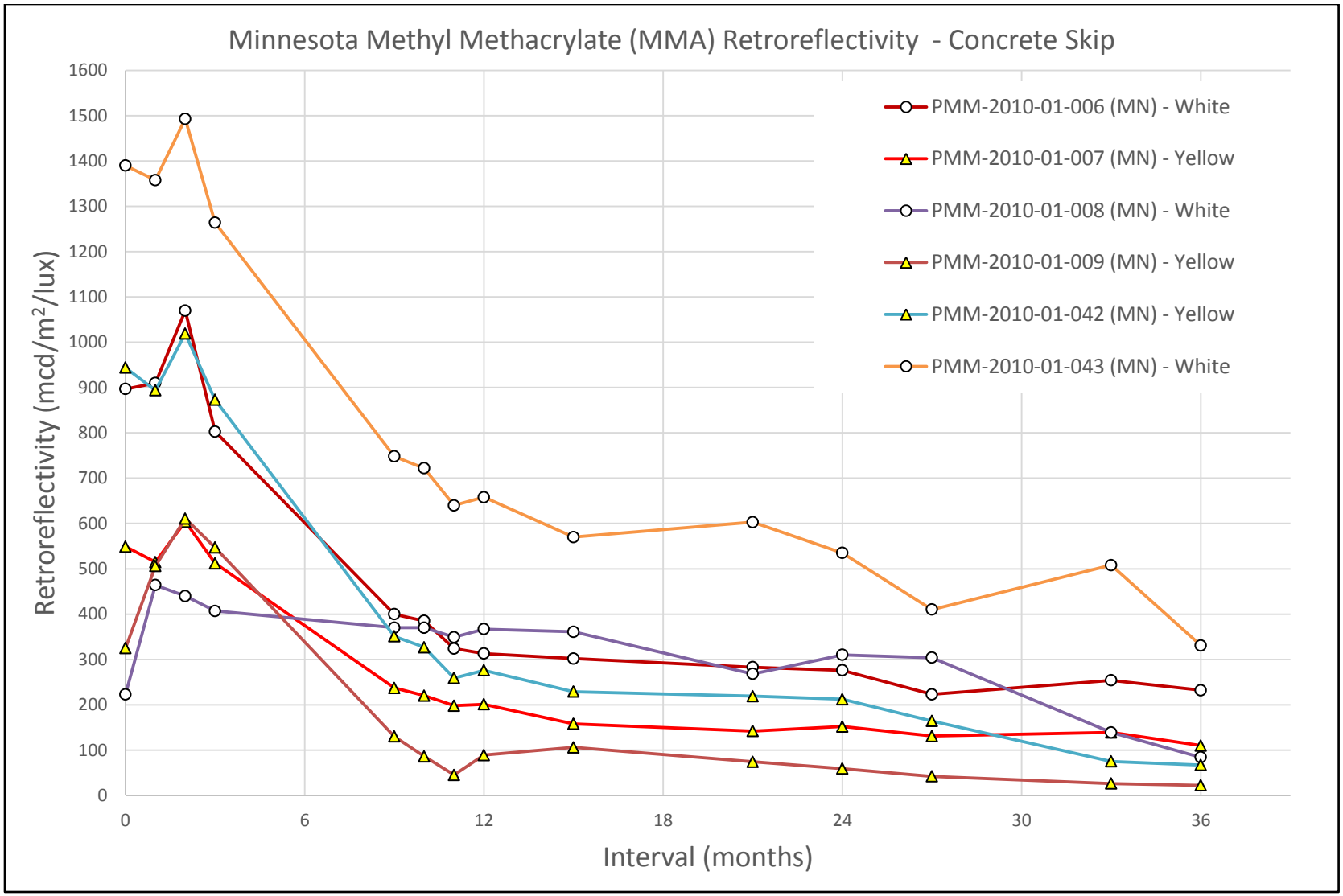

Figure 20. Retroreflectivity of MMA Materials on Concrete on Minnesota Test Deck (Skip Location)

(Source: NTPEP Datamine)

Due to the higher number of MMA markings on the Pennsylvania test decks, the graphs of MMA in Pennsylvania are also separated by color to make them easier to read. The retroreflectivity performance of the white and yellow Pennsylvania MMA markings on the asphalt and the concrete surfaced roadways are shown in Figure 21 through Figure 24 and are summarized here:

- Products 085 and 086 likely have higher initial retoreflectivity values because they are structured MMA markings with Swarco Megalux and Duralux beads.
- Product 065 and 066 used a single drop of a multicoated Type 0 and Type 1 bead, respectively, at an application rate of 8 lbs/gallon. No obvious factor was identified to explain why this product had higher retroreflectivity values than others.
- Like other marking materials, the MMA yellow markings have lower retroreflectivity values than their white counterparts.

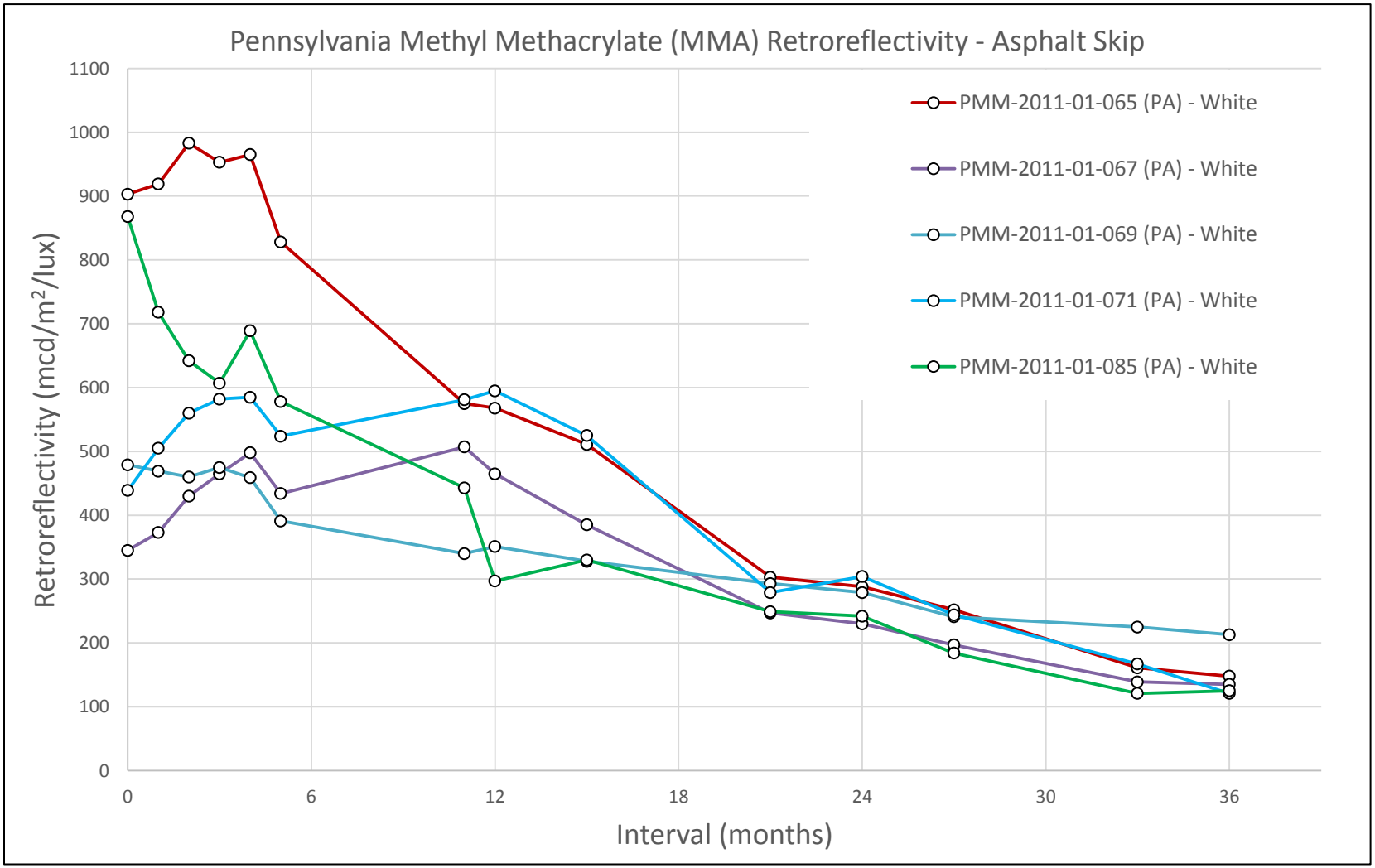

Figure 21. Retroreflectivity of White MMA Materials on Asphalt on Pennsylvania Test Deck (Skip Location)
(Source: NTPEP Datamine)

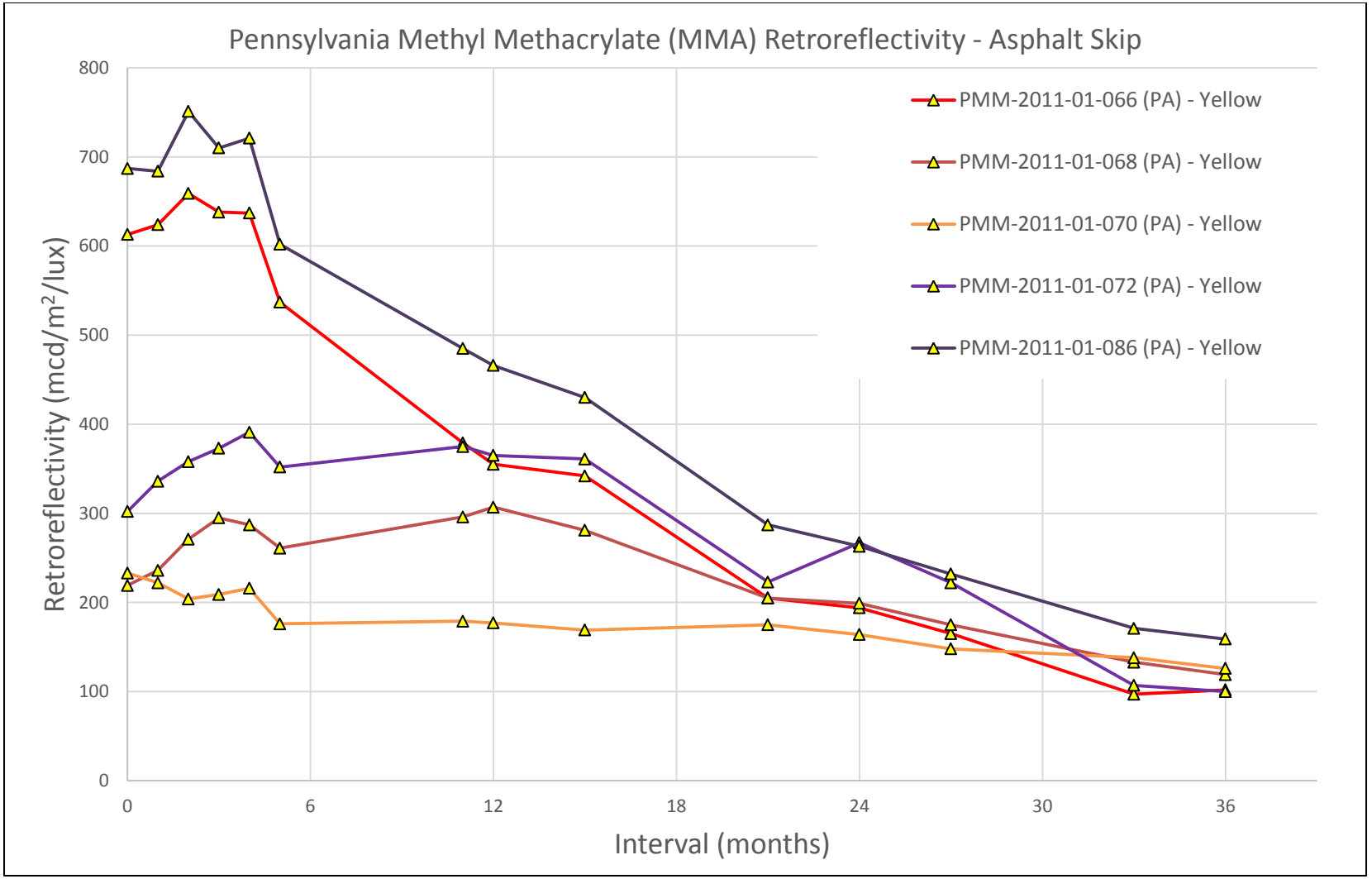

Figure 22. Retroreflectivity of Yellow MMA Materials on Asphalt on Pennsylvania Test Deck (Skip Location)
(Source: NTPEP Datamine)

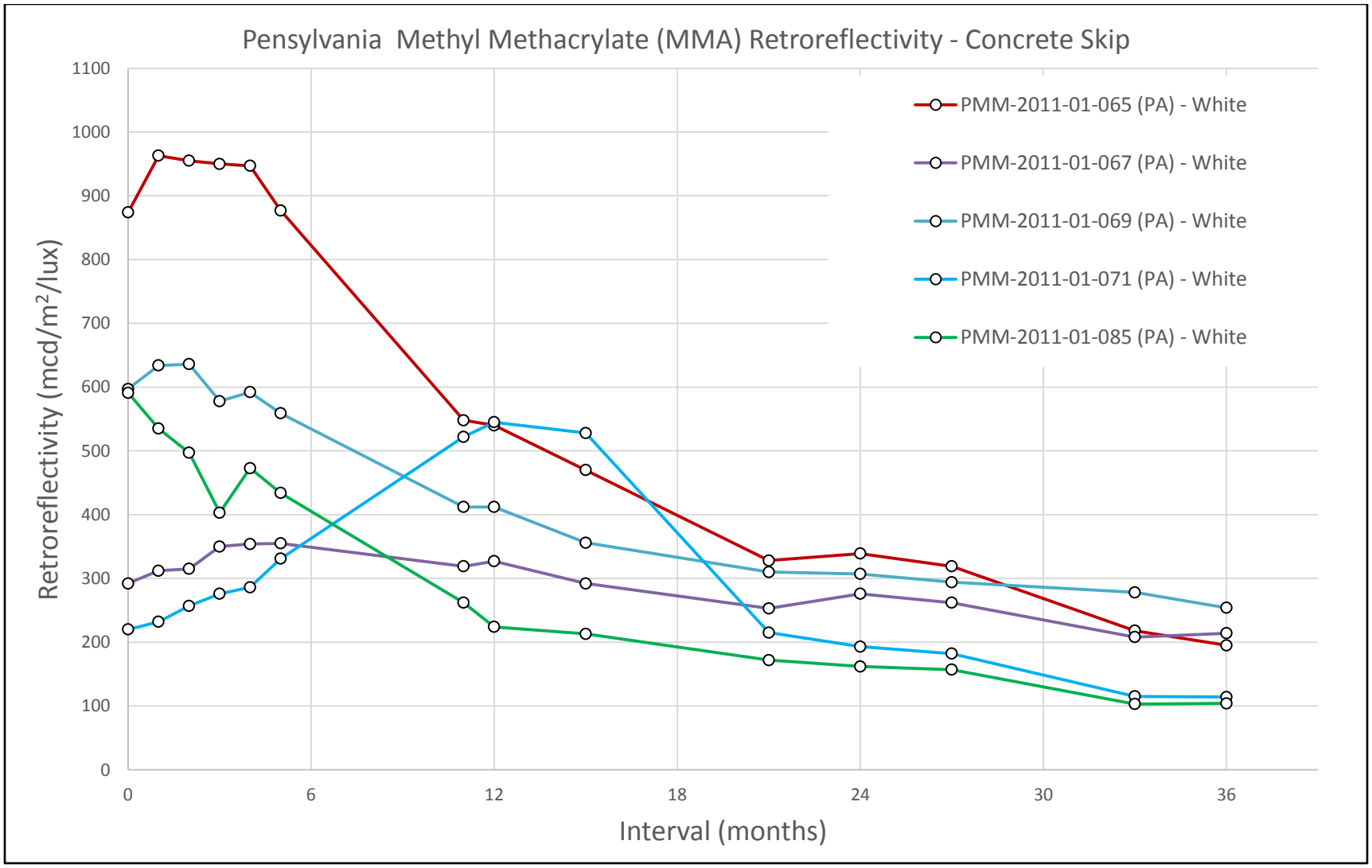

Figure 23. Retroreflectivity of White MMA Materials on Concrete on Pennsylvania Test Deck (Skip Location)
(Source: NTPEP Datamine)

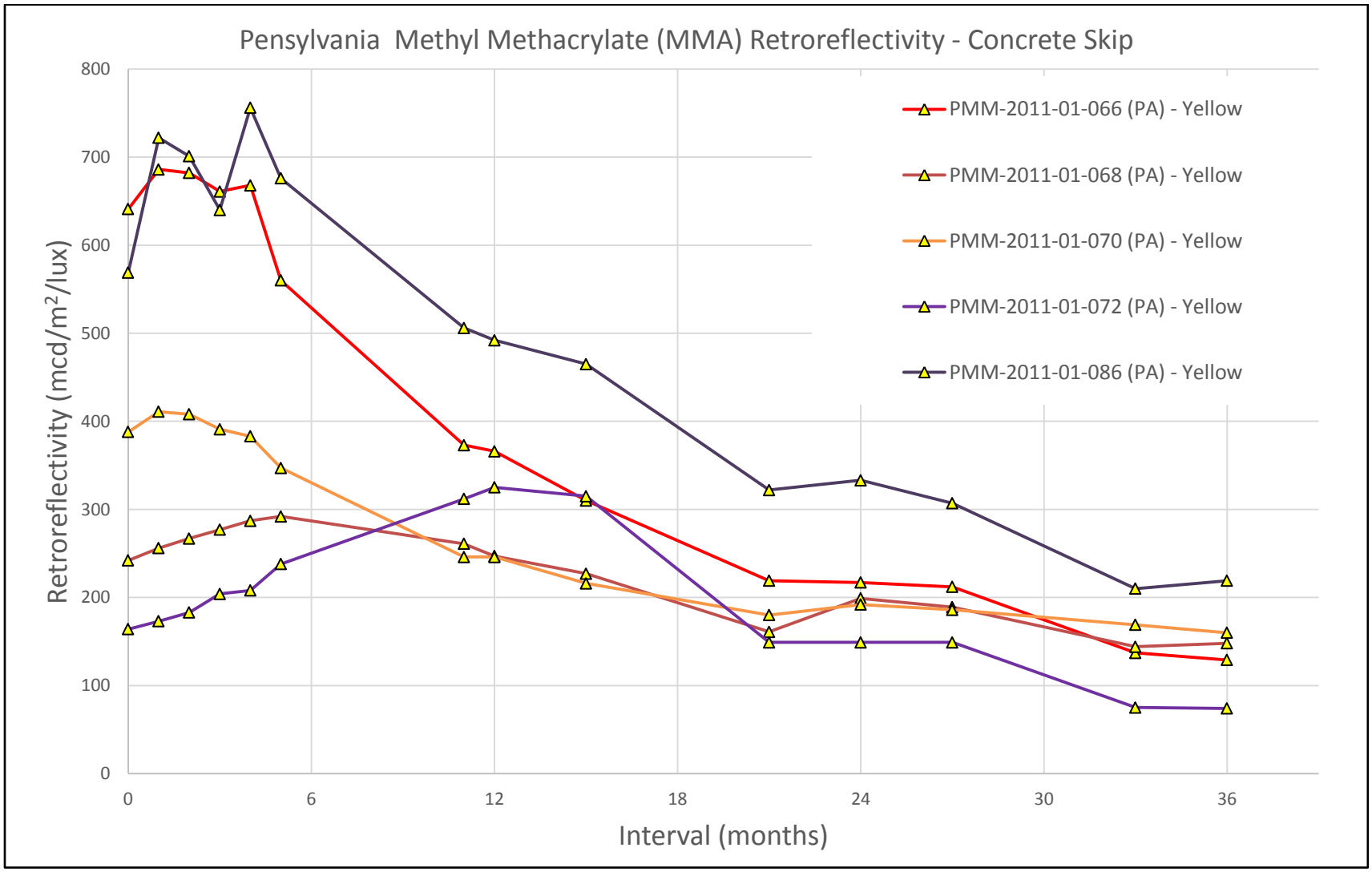

Figure 24. Retroreflectivity of Yellow MMA Materials on Concrete on Pennsylvania Test Deck (Skip Location)
(Source: NTPEP Datamine)

The retroreflectivity performance of the Florida MMA markings on the asphalt and the concrete surfaced roadways are shown in Figure 25 and Figure 26, respectively, and are summarized here:

- Products 082 and 083 had intermix beads, which may explain some of the repeated increasing and decreasing retroreflectivity values.
- All but one yellow marking had retroreflectivity values over 100 mcd after three years.
- Like other marking materials, the MMA yellow markings have lower retroreflectivity values than their white counterparts.

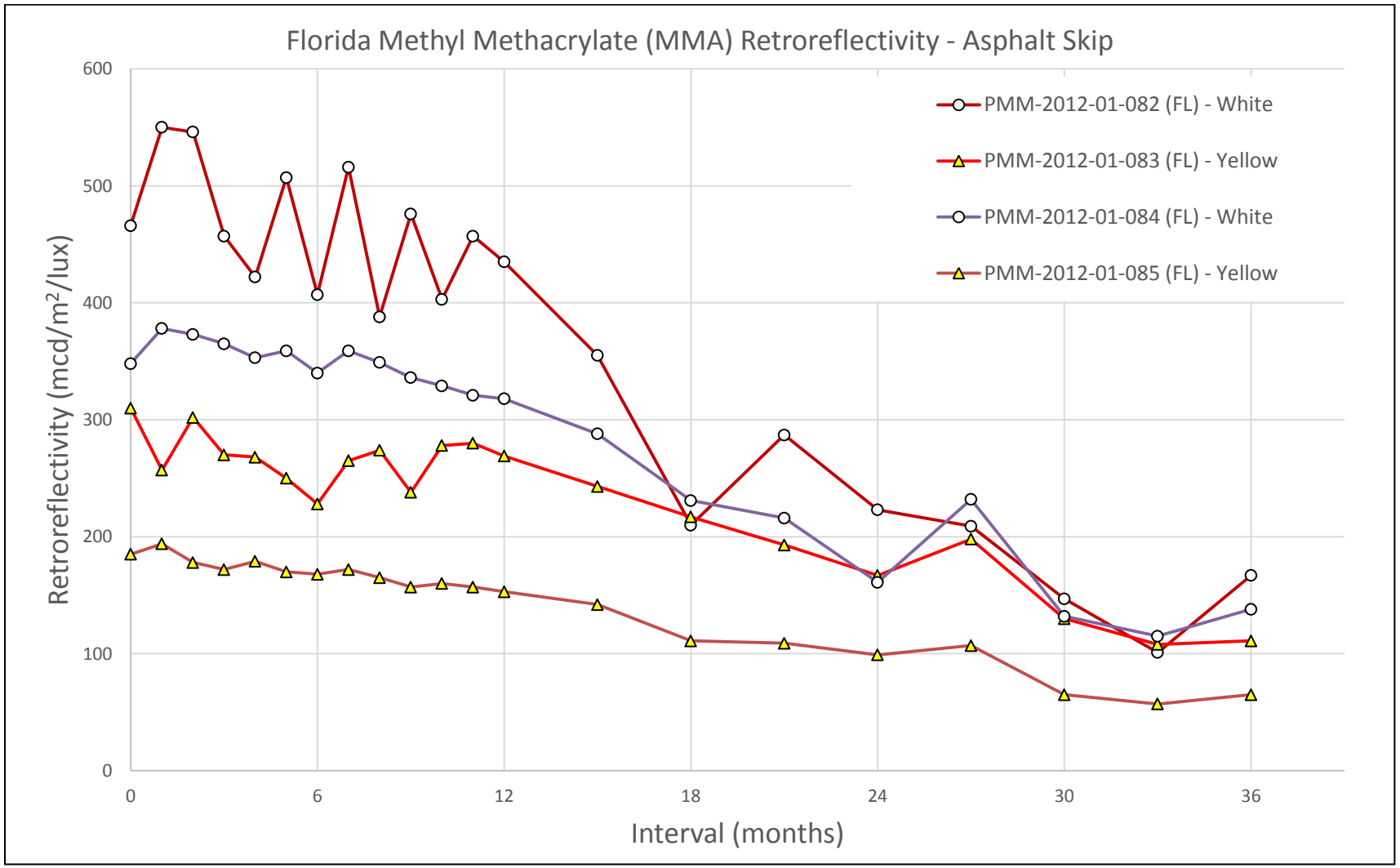

Figure 25. Retroreflectivity of MMA Materials on Asphalt on Florida Test Deck (Skip Location)
(Source: NTPEP Datamine)

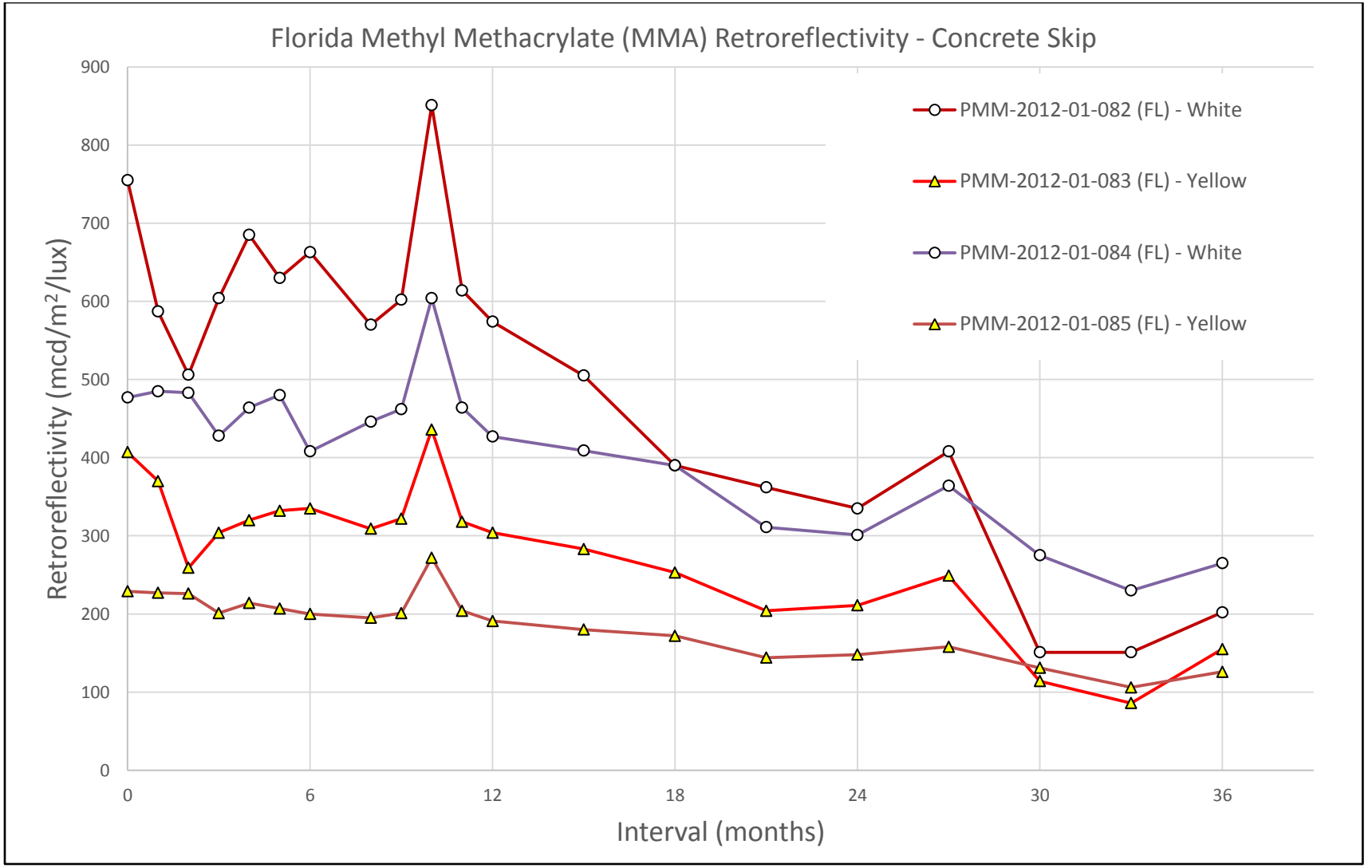

Figure 26. Retroreflectivity of MMA Materials on Concrete on Florida Test Deck (Skip Location)
(Source: NTPEP Datamine)

Currently there are no federal minimum maintained retroreflectivity standards, but for this analysis the research team chose four performance ratings and corresponding retroreflectivity threshold values as shown in Table 5. The criteria for the ratings were separated for lower speed roadways (>35 MPH and < 70 MPH) and higher speed roadways (≥ 70 MPH). The final retroreflectivity values recorded at the 36-month assessment were evaluated according to this rating scale and are summarized in Table 6, where Good ratings are highlighted in yellow.

Table 5. Retroreflectivity Performance Ratings and Corresponding Threshold Values Used in This Study's Analysis

Ratings	Low speed (>35 and <70PMH)		High speed (≥70MPH)	
	Yellow	White	Yellow	White
Good	175	250	175	250
Fair	100	150	125	175
Poor	50	50	100	100
Fail	≤ 50	≤ 50	≤ 100	≤ 100

Table 6. Retroreflectivity Performance Rating Summary of NTPEP Pavement Marking Data for Florida, Minnesota, and Pennsylvania Test Decks
("Good" ratings are highlighted in yellow.)

NTPEP Code (State)	Product Type	Color	Speed < 70 MPH		Speed ≥ 70 MPH	
			Asphalt Retroreflectivity Rating	Concrete Retroreflectivity Rating	Asphalt Retroreflectivity Rating	Concrete Retroreflectivity Rating
PMM-2010-01-046 (MN)	Epoxy	Yellow	Fair	Fair	Fair	Fair
PMM-2010-01-047 (MN)	Epoxy	White	Fair	Fair	Fair	Fair
PMM-2011-01-087 (PA)	Epoxy	White	Fair	Good	Fair	Good
PMM-2011-01-088 (PA)	Epoxy	White	Fair	Fair	Poor	Fair
PMM-2011-01-089 (PA)	Epoxy	Yellow	Fair	Fair	Poor	Fair
PMM-2011-01-092 (PA)	Epoxy	Yellow	Fair	Good	Fair	Good
PMM-2010-01-058 (MN)	Polyurea	White	Fair	Fair	Fair	Fair
PMM-2010-01-059 (MN)	Polyurea	Yellow	Fail	Fail	Fail	Fail
PMM-2010-01-060 (MN)	Polyurea	White	Fair	Good	Fair	Good
PMM-2010-01-061 (MN)	Polyurea	Yellow	Poor	Poor	Fail	Fail
PMM-2012-01-038 (FL)	Polyurea	White	Fair	Good	Fair	Good
PMM-2012-01-039 (FL)	Polyurea	Yellow	Fair	Good	Fair	Good
PMM-2010-01-040 (MN)	Thermoplastic	Yellow	Fair	Fail	Poor	Fail
PMM-2010-01-041 (MN)	Thermoplastic	White	Fair	Fail	Fair	Fail
PMM-2011-01-047 (PA)	Thermoplastic	White	Fair	Fair	Fair	Fair
PMM-2011-01-048 (PA)	Thermoplastic	Yellow	Poor	Fair	Fail	Poor
PMM-2011-01-049 (PA)	Thermoplastic	White	Fair	Fair	Fair	Fair
PMM-2011-01-050 (PA)	Thermoplastic	Yellow	Poor	Fair	Fail	Poor

NTPEP Code (State)	Product Type	Color	Speed < 70 MPH		Speed ≥ 70 MPH	
			Asphalt Retroreflectivity Rating	Concrete Retroreflectivity Rating	Asphalt Retroreflectivity Rating	Concrete Retroreflectivity Rating
PMM-2011-01-063 (PA)	Thermoplastic	Yellow	Poor	Fair	Fail	Fair
PMM-2011-01-064 (PA)	Thermoplastic	Yellow	Fail	Fair	Fail	Poor
PMM-2011-01-103 (PA)	Thermoplastic	White	Good	Fair	Good	Fair
PMM-2011-01-104 (PA)	Thermoplastic	Yellow	Poor	Fail	Fail	Fail
PMM-2011-01-105 (PA)	Thermoplastic	White	Fair	Fair	Fair	Fair
PMM-2011-01-106 (PA)	Thermoplastic	Yellow	Poor	Fail	Fail	Fail
PMM-2012-01-001 (FL)	Thermoplastic	White	Good	Good	Good	Good
PMM-2012-01-002 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good
PMM-2012-01-003 (FL)	Thermoplastic	White	Good	Good	Good	Good
PMM-2012-01-004 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good
PMM-2012-01-019 (FL)	Thermoplastic	White	Good	Good	Good	Good
PMM-2012-01-022 (FL)	Thermoplastic	White	Good	Good	Good	Good
PMM-2012-01-024 (FL)	Thermoplastic	Yellow	Fair	Poor	Fair	Fail
PMM-2012-01-025 (FL)	Thermoplastic	Yellow	Fair	Fair	Fair	Poor
PMM-2012-01-031 (FL)	Thermoplastic	White	Good	Good	Good	Good
PMM-2012-01-032 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good
PMM-2012-01-033 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good
PMM-2012-01-043 (FL)	Thermoplastic	White	Fair	Good	Fair	Good
PMM-2012-01-044 (FL)	Thermoplastic	Yellow	Fair	Fair	Fair	Fair
PMM-2012-01-045 (FL)	Thermoplastic	White	Fair	Good	Fair	Good
PMM-2012-01-046 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good
PMM-2012-01-053 (FL)	Thermoplastic	White	Fair	Good	Fair	Good
PMM-2012-01-054 (FL)	Thermoplastic	Yellow	Fair	Fair	Fair	Fair
PMM-2012-01-055 (FL)	Thermoplastic	White	Fair	Good	Fair	Good
PMM-2012-01-056 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good
PMM-2010-01-006 (MN)	MMA	White	Fair	Fair	Fair	Fair
PMM-2010-01-007 (MN)	MMA	Yellow	Fair	Fair	Fair	Poor
PMM-2010-01-008 (MN)	MMA	White	Fair	Poor	Fair	Fail
PMM-2010-01-009 (MN)	MMA	Yellow	Poor	Fail	Fail	Fail
PMM-2010-01-042 (MN)	MMA	Yellow	Fair	Poor	Fair	Fail
PMM-2010-01-043 (MN)	MMA	White	Good	Good	Good	Good
PMM-2011-01-065 (PA)	MMA	White	Poor	Fair	Poor	Fair
PMM-2011-01-066 (PA)	MMA	Yellow	Fair	Fair	Poor	Fair
PMM-2011-01-067 (PA)	MMA	White	Poor	Fair	Poor	Fair
PMM-2011-01-068 (PA)	MMA	Yellow	Fair	Fair	Poor	Fair
PMM-2011-01-069 (PA)	MMA	White	Fair	Good	Fair	Good
PMM-2011-01-070 (PA)	MMA	Yellow	Fair	Fair	Fair	Fair
PMM-2011-01-071 (PA)	MMA	White	Poor	Poor	Poor	Poor
PMM-2011-01-072 (PA)	MMA	Yellow	Fair	Poor	Fail	Fail
PMM-2011-01-085 (PA)	MMA	White	Poor	Poor	Poor	Poor

NTPEP Code (State)	Product Type	Color	Speed < 70 MPH		Speed ≥ 70 MPH	
			Asphalt Retroreflectivity Rating	Concrete Retroreflectivity Rating	Asphalt Retroreflectivity Rating	Concrete Retroreflectivity Rating
PMM-2011-01-086 (PA)	MMA	Yellow	Fair	Good	Fair	Good
PMM-2012-01-082 (FL)	MMA	White	Fair	Fair	Poor	Fair
PMM-2012-01-083 (FL)	MMA	Yellow	Fair	Fair	Poor	Fair
PMM-2012-01-084 (FL)	MMA	White	Poor	Good	Poor	Good
PMM-2012-01-085 (FL)	MMA	Yellow	Poor	Fair	Fail	Fair
PMM-2010-01-044 (MN)	Urethane	Yellow	Fair	Fair	Fair	Fair
PMM-2010-01-045 (MN)	Urethane	White	Fair	Fair	Fair	Fair
PMM-2010-01-062 (MN)	Urethane	White	Fair	Fair	Fair	Poor
PMM-2010-01-063 (MN)	Urethane	Yellow	Fair	Poor	Poor	Fail
PMM-2011-01-083 (PA)	Urethane	White	Fair	Good	Fair	Good
PMM-2011-01-084 (PA)	Urethane	Yellow	Fair	Good	Fair	Good

Durability

The NTPEP definitions and procedures for measuring durability are as follows:

"This is a rating on a one (1) to ten (10) scale with ten (10) being the best. Durability is obtained by examining an eighteen (18) inch length of line centered on the wheel track area, reported as "wheel" in the database and the nine (9) inches of skip line area, reported as "skip" in the database. A percentage of the marking material remaining in this area is translated to a one (1) to ten (10) scale. Durability is conducted according to ASTM D 913. The reported value is the average of the four (4) values for both areas. This data can be used to determine the "toughness" of a pavement marking binder under long-term field conditions and weathering. It judges only the amount of binder retained on the evaluation surface. Retention of beads to this binder is NOT implied. Durability can be used in conjunction with retroreflectivity to provide an overall snapshot of the performance of a marking material at various points during service life." - *NTPEP Pavement Marking Materials Data Usage Guide*

Figure 27 provides three examples of durability ratings.

Figure 27. Pavement Marking Durability Rating Example Photographs Showing Wear on Pavement Stripes
(From *NTPEP Pavement Marking Materials Data Usage Guide*)

Pavement markings will always start at a maximum durability rating of 10 and deteriorate over time, with larger drops occurring due to abrasion from snow plow blades. Markings will likely need to be restriped when they reach a rating of 5. A durability performance rating of “Good” was assigned to durability values from 10 to 8, “Fair” to values of 7 and 6, and “Poor” to values of 5 and below. The NTPEP durability data is presented in Table 7 (Asphalt Surfaced Pavements) and

Table **8** (Concrete Surfaced Pavements) with highlighting to show where the performance over time fell within the assigned ranges. The final durability performance rating (at 36 months) is also included in the table.

Analysis of the NTPEP data across the three states selected shows that Florida markings were much less likely to show extreme wear than those in the colder states (Minnesota and Pennsylvania). Only four thermoplastic materials in Florida experienced any deterioration of durability, all of which were on concrete pavement. Thermoplastics markings in Minnesota and Pennsylvania also experienced greater wear (loss of durability) on concrete. Epoxy and polyurea materials performed fairly well on both pavement types, with epoxies performing slightly better on asphalt and polyureas performing slightly better on concrete.

Color Key

Good	10 to 8
Fair	7 to 6
Poor	5 to 0

Table 7. Data for Pavement Marking Durability on Asphalt on Skip from Florida, Minnesota, and Pennsylvania Test Decks with Performance Rating

(Source: NTPEP Datamine)

NTPEP Code (State)	Product Type	Color	Durability on Asphalt – Skip, Intervals in Months																				Rating
			0	1	2	3	4	5	6	7	8	9	10	11	12	15	18	21	24	27	30	33	36	
PMM-2010-01-046 (MN)	Epoxy	Yellow	10	10	10	10						7	9	9	8	8		8	8	8		7	7	Fair
PMM-2010-01-047 (MN)	Epoxy	White	10	10	10	10						8	8	8	8	8		8	8	7		7	6	Fair
PMM-2011-01-087 (PA)	Epoxy	White	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good
PMM-2011-01-088 (PA)	Epoxy	White	10	10	10	10	10	10						9	9	9		9	9	9		8	8	Good
PMM-2011-01-089 (PA)	Epoxy	Yellow	10	10	10	10	10	10						9	9	9		9	9	9		8	8	Good
PMM-2011-01-092 (PA)	Epoxy	Yellow	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good
PMM-2010-01-058 (MN)	Polyurea	White	10	10	10	10						8	9	9	9	9		8	9	8		7	7	Fair
PMM-2010-01-059 (MN)	Polyurea	Yellow	10	10	10	10						6	6	6	7	6		7	6	6		5	5	Poor
PMM-2010-01-060 (MN)	Polyurea	White	10	10	10	10						8	9	9	9	8		8	8	8		8	7	Fair
PMM-2010-01-061 (MN)	Polyurea	Yellow	10	10	10	10						8	9	9	9	9		9	9	9		8	8	Good
PMM-2012-01-038 (FL)	Polyurea	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-039 (FL)	Polyurea	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2010-01-040 (MN)	Thermoplastic	Yellow	10	10	10	10						9	9	9	9	8		8	7	7		6	6	Fair
PMM-2010-01-041 (MN)	Thermoplastic	White	10	10	10	10						8	8	8	8	8		8	7	7		5	5	Poor
PMM-2011-01-047 (PA)	Thermoplastic	White	10	10	10	10	10	10						10	10	10		9	9	9		8	8	Good
PMM-2011-01-048 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						10	10	10		9	9	9		8	8	Good
PMM-2011-01-049 (PA)	Thermoplastic	White	10	10	10	10	10	10						10	10	10		9	9	9		7	7	Fair
PMM-2011-01-050 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						10	10	10		9	9	9		6	6	Fair
PMM-2011-01-063 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		7	7	7		6	5	Poor
PMM-2011-01-064 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		7	7	6		4	3	Poor
PMM-2011-01-103 (PA)	Thermoplastic	White	10	10	10	10	10	10						10	10	10		9	9	9		8	8	Good
PMM-2011-01-104 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		8	8	8		7	6	Fair
PMM-2011-01-105 (PA)	Thermoplastic	White	10	10	10	10	10	10						10	10	10		9	9	9		8	7	Fair
PMM-2011-01-106 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		8	8	8		7	6	Fair
PMM-2012-01-001 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-002 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-003 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-004 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good

NTPEP Code (State)	Product Type	Color	Durability on Asphalt – Skip, Intervals in Months																					Rating
PMM-2012-01-019 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10		10	10	10		10	10	10	10	10	Good
PMM-2012-01-022 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10		10	10	10		10	10	10	10	10	Good
PMM-2012-01-024 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10		10	10	10		10	10	10	10	10	Good
PMM-2012-01-025 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		10	10	10	10	10	Good
PMM-2012-01-031 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-032 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-033 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-043 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-044 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-045 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-046 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-053 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-054 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-055 (FL)	Thermoplastic	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-056 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2010-01-006 (MN)	MMA	White	10	10	10	10						9	9	8	8	7		7	7	7		6	6	Fair
PMM-2010-01-007 (MN)	MMA	Yellow	10	10	10	10						9	9	9	8	9		8	8	8		7	7	Fair
PMM-2010-01-008 (MN)	MMA	White	10	10	10	10						9	9	9	8	8		8	8	8		7	7	Fair
PMM-2010-01-009 (MN)	MMA	Yellow	10	10	10	10						10	10	9	9	9		9	9	9		8	8	Good
PMM-2010-01-042 (MN)	MMA	Yellow	10	10	10	10						8	7	8	7	7		6	6	6		5	4	Poor
PMM-2010-01-043 (MN)	MMA	White	10	10	10	10						7	7	7	6	6		5	6	6		5	4	Poor
PMM-2011-01-065 (PA)	MMA	White	7	7	7	7	7	7						7	7	7		6	6	6		5	4	Poor
PMM-2011-01-066 (PA)	MMA	Yellow	8	8	8	8	8	8						8	8	8		5	5	5		4	4	Poor
PMM-2011-01-067 (PA)	MMA	White	10	10	10	10	10	10						9	9	9		8	8	8		7	7	Fair
PMM-2011-01-068 (PA)	MMA	Yellow	10	10	10	10	10	10						9	9	9		8	8	8		7	7	Fair
PMM-2011-01-069 (PA)	MMA	White	8	8	8	8	8	8						8	8	8		8	8	8		8	7	Fair
PMM-2011-01-070 (PA)	MMA	Yellow	8	8	8	8	8	8						8	8	8		8	8	8		7	7	Fair
PMM-2011-01-071 (PA)	MMA	White	10	10	10	10	10	10						10	10	10		10	10	10		9	8	Good
PMM-2011-01-072 (PA)	MMA	Yellow	10	10	10	10	10	10						10	10	10		10	10	10		9	9	Good
PMM-2011-01-085 (PA)	MMA	White	8	8	8	8	8	8						8	8	8		7	7	7		6	6	Fair
PMM-2011-01-086 (PA)	MMA	Yellow	8	8	8	8	8	8						8	8	8		8	8	8		7	6	Fair
PMM-2012-01-082 (FL)	MMA	White	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	Good
PMM-2012-01-083 (FL)	MMA	Yellow	8	8	8	8	8	8	8	8	8	8	8	8	8	9	8	8	8	8	8	8	8	Good
PMM-2012-01-084 (FL)	MMA	White	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-085 (FL)	MMA	Yellow	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2010-01-044 (MN)	Urethane	Yellow	10	10	10	10						7	9	9	8	8		8	8	8		8	7	Fair

NTPEP Code (State)	Product Type	Color	Durability on Asphalt – Skip, Intervals in Months																					Rating
PMM-2010-01-045 (MN)	Urethane	White	10	10	10	10						8	8	8	8	8		7	7	7		6	7	Fair
PMM-2010-01-062 (MN)	Urethane	White	10	10	10	10						8	9	9	9	9		9	8	8		8	7	Fair
PMM-2010-01-063 (MN)	Urethane	Yellow	10	10	10	10						9	9	10	9	9		9	8	8		8	7	Fair
PMM-2011-01-083 (PA)	Urethane	White	10	9	9	9	9	9						9	9	9		9	9	9		9	9	Good
PMM-2011-01-084 (PA)	Urethane	Yellow	10	9	9	9	9	9						9	9	9		9	9	9		9	9	Good

Color Key

	10 to 8
	7 to 6
	5 to 0

Table 8. Data for Pavement Marking Durability on Concrete on Skip from Florida, Minnesota, and Pennsylvania Test Decks with Performance Rating

(Source: NTPEP Datamine)

NTPEP Code (State)	Product Type	Color	urability on Concrete Pavement - Skip, Intervals in Months																				Rating
			0	1	2	3	4	5	6	7	8	9	10	11	12	15	18	21	24	27	30	33	36	
PMM-2010-01-046 (MN)	Epoxy	Yellow	10	10	10	10						10	9	9	9	9		8	8	7		4	5	Poor
PMM-2010-01-047 (MN)	Epoxy	White	10	10	10	10						9	9	8	9	8		8	7	7		6	6	Fair
PMM-2011-01-087 (PA)	Epoxy	White	10	10	10	10	10	10						10	10	10		9	9	9		9	9	Good
PMM-2011-01-088 (PA)	Epoxy	White	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good
PMM-2011-01-089 (PA)	Epoxy	Yellow	10	10	10	10	10	10						10	10	10		9	9	9		9	9	Good
PMM-2011-01-092 (PA)	Epoxy	Yellow	10	10	10	10	10	10						10	10	10		9	9	9		9	9	Good
PMM-2010-01-058 (MN)	Polyurea	White	10	10	10	10						10	10	9	9	9		9	9	9		8	8	Good
PMM-2010-01-059 (MN)	Polyurea	Yellow	10	10	10	10						10	10	9	9	9		8	8	8		8	8	Good
PMM-2010-01-060 (MN)	Polyurea	White	10	10	10	10						10	10	9	10	9		9	9	9		9	9	Good
PMM-2010-01-061 (MN)	Polyurea	Yellow	10	10	10	10						10	10	9	10	9		9	9	9		9	9	Good
PMM-2012-01-038 (FL)	Polyurea	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-039 (FL)	Polyurea	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2010-01-040 (MN)	Thermoplastic	Yellow	10	10	10	10						0	1	0	0	0		1	0	0		0	0	Poor
PMM-2010-01-041 (MN)	Thermoplastic	White	10	10	10	10						2	2	2	2	1		0	1	0		0	0	Poor
PMM-2011-01-047 (PA)	Thermoplastic	White	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good
PMM-2011-01-048 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		9	8	8		8	7	Fair
PMM-2011-01-049 (PA)	Thermoplastic	White	10	10	10	10	10	10						9	9	9		9	9	9		8	8	Good
PMM-2011-01-050 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		9	9	9		8	8	Good
PMM-2011-01-063 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						10	10	10		9	9	9		9	9	Good
PMM-2011-01-064 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						10	10	9		9	9	9		9	9	Good
PMM-2011-01-103 (PA)	Thermoplastic	White	10	10	10	10	10	10						9	9	9		8	8	8		6	5	Poor
PMM-2011-01-104 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		8	7	7		1	1	Poor
PMM-2011-01-105 (PA)	Thermoplastic	White	10	10	10	10	10	10						9	9	9		9	8	8		5	5	Poor
PMM-2011-01-106 (PA)	Thermoplastic	Yellow	10	10	10	10	10	10						9	9	9		8	7	7		1	1	Poor
PMM-2012-01-001 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-002 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-003 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-004 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good

NTPEP Code (State)	Product Type	Color	urability on Concrete Pavement - Skip, Intervals in Months																					Rating
PMM-2012-01-019 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10		10	10	10		10	10	9	5	5	Poor
PMM-2012-01-022 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10		10	10	10		10	10	10	8	8	Good
PMM-2012-01-024 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10		10	9	10		9	9	7	4	4	Poor
PMM-2012-01-025 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10		10	9	10		9	9	7	4	4	Poor
PMM-2012-01-031 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-032 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-033 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-043 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-044 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-045 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-046 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-053 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-054 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-055 (FL)	Thermoplastic	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-056 (FL)	Thermoplastic	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2010-01-006 (MN)	MMA	White	10	10	10	10						9	9	8	9	8		7	7	7		6	6	Fair
PMM-2010-01-007 (MN)	MMA	Yellow	10	10	10	10						9	8	8	8	8		8	8	7		6	7	Fair
PMM-2010-01-008 (MN)	MMA	White	10	10	10	10						8	6	7	7	7		7	7	6		3	2	Poor
PMM-2010-01-009 (MN)	MMA	Yellow	10	10	10	10						3	3	2	2	2		2	2	2		1	1	Poor
PMM-2010-01-042 (MN)	MMA	Yellow	10	10	10	10						6	8	6	7	6		5	5	5		4	2	Poor
PMM-2010-01-043 (MN)	MMA	White	10	10	10	10						7	8	7	8	7		6	6	6		5	4	Poor
PMM-2011-01-065 (PA)	MMA	White	8	8	8	8	8	8						8	8	8		7	7	7		5	5	Poor
PMM-2011-01-066 (PA)	MMA	Yellow	7	7	7	7	7	7						7	7	7		6	6	6		4	4	Poor
PMM-2011-01-067 (PA)	MMA	White	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good
PMM-2011-01-068 (PA)	MMA	Yellow	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good
PMM-2011-01-069 (PA)	MMA	White	8	8	8	8	8	8						8	8	8		8	8	8		8	8	Good
PMM-2011-01-070 (PA)	MMA	Yellow	8	8	8	8	8	8						8	8	8		8	8	8		8	7	Fair
PMM-2011-01-071 (PA)	MMA	White	10	10	10	10	10	10						10	10	10		10	10	10		9	9	Good
PMM-2011-01-072 (PA)	MMA	Yellow	10	10	10	10	10	10						10	10	10		10	10	10		9	9	Good
PMM-2011-01-085 (PA)	MMA	White	8	8	7	7	7	7						7	7	7		6	6	6		4	4	Poor
PMM-2011-01-086 (PA)	MMA	Yellow	8	8	8	8	8	8						8	8	8		8	8	8		8	8	Good
PMM-2012-01-082 (FL)	MMA	White	8	8	8	8	8	8	8		8	8	8	8	8	8	8	8	8	8	8	8	8	Good
PMM-2012-01-083 (FL)	MMA	Yellow	8	8	8	8	8	8	8		8	8	8	8	8	8	8	8	8	8	8	8	8	Good
PMM-2012-01-084 (FL)	MMA	White	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2012-01-085 (FL)	MMA	Yellow	10	10	10	10	10	10	10		10	10	10	10	10	10	10	10	10	10	10	10	10	Good
PMM-2010-01-044 (MN)	Urethane	Yellow	10	10	10	10						10	10	9	9	8		9	9	8		8	7	Fair

NTPEP Code (State)	Product Type	Color	urability on Concrete Pavement - Skip, Intervals in Months																					Rating
PMM-2010-01-045 (MN)	Urethane	White	10	10	10	10						10	9	9	9	9		8	8	7		5	6	Fair
PMM-2010-01-062 (MN)	Urethane	White	10	10	10	10						10	9	9	9	9		9	8	8		5	5	Poor
PMM-2010-01-063 (MN)	Urethane	Yellow	10	10	10	10						9	9	8	8	9		8	8	7		3	3	Poor
PMM-2011-01-083 (PA)	Urethane	White	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good
PMM-2011-01-084 (PA)	Urethane	Yellow	10	10	10	10	10	10						9	9	9		9	9	9		9	9	Good

Daytime Color

The NTPEP method specified for measuring daytime color of pavement marking materials requires the use of a spectrophotometer according to ASTM D 6628, Standard Specification for Color of Pavement Marking Materials. Data is recorded using the Commission Internationale de I'Eclairage (CIE) Y, x, y color space measured with a 2 degree observer using a D65 Illuminant (*NTPEP Committee Work Plan for Field Evaluation Of Pavement Marking Materials)*. This color space is defined in two parts, lightness (Y) and hue (xy). Lightness is a measure of how light or dark a color is. Hue is the term used for the classification of a color such as red, yellow, blue, etc. The CIE x,y chromaticity diagram is shown in Figure 28.

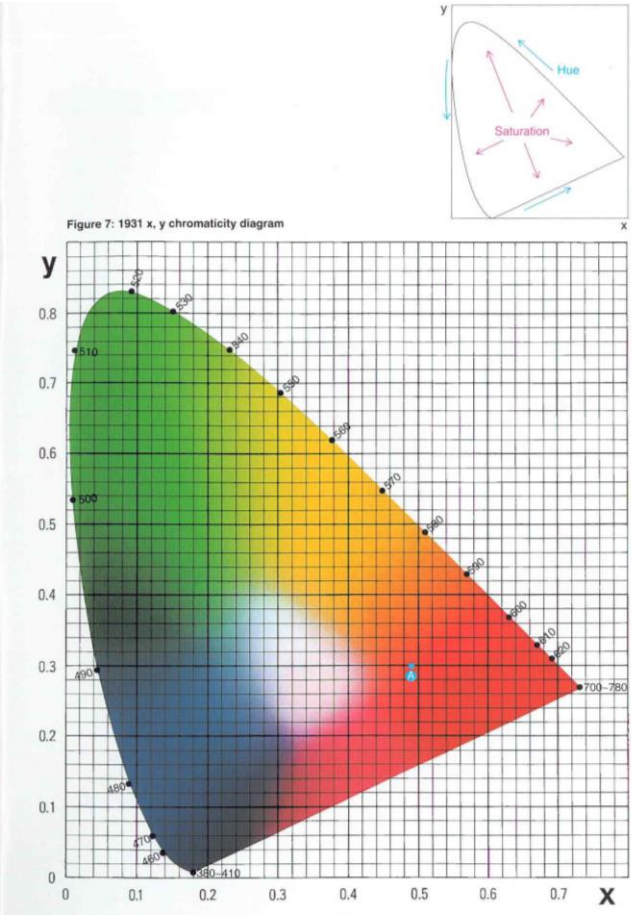

Figure 28. CIE x,y chromaticity diagram.
(From "Precise Color Communication" pamphlet by Konica Minolta)

Lightness, Y, can be thought of as a value along a third axis perpendicular to the chromaticity diagram. For an example, in Yxy color space point A in Figure 28 has the following color coordinates:

$$Y = 13.37, x = 0.4832, y = 0.3045$$

Per ASTM D 6628, the in-service daytime lightness (Y) limit for white is a minimum of 35 and the limit for yellow is a minimum of 25. Also, a pavement marking material's color coordinates must plot within the

chromaticity limits of the polygons in Figure 29 throughout its service life. The corner points that define the boundaries of these limits are listed in Table 9.

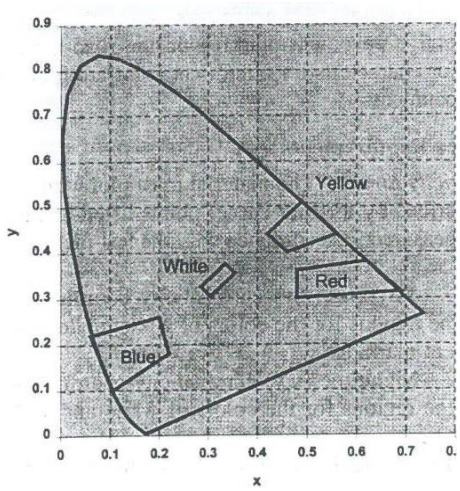

Figure 29. Chromaticity limits of pavement markings.
(From ASTM D 6628-03)

Table 9. Chromaticity Corner Points of Pavement Markings
(From ASTM D 6628-03)

Color	Chromaticity Coordinates (Corner Points)							
	1		2		3		4	
	x	y	x	y	x	y	x	y
White	0.355	0.355	0.305	0.305	0.285	0.325	0.335	0.375
Yellow	0.560	0.440	0.490	0.510	0.420	0.440	0.460	0.400

Analysis of NTPEP daytime color data is fairly straightforward. The lightness values (Y) were checked for meeting minimum requirements. The hue values (x,y) were plotted on the chromaticity diagram and marked if they fell outside the appropriate limits. Table 10 provides a summary of marking material color performance by counts of how many tests failed the lightness and hue checks, and the material age at the earliest failure for each analysis variable was recorded. It is possible for lightness (Y) values to drop below the established minimum and and come back up in subsequent tests. Similar trends can occur in hue (xy) data but it is more likely for hue data to continue to fall away from the chromaticity limits over time.

The overall color performance rating in Table 10 considers both lightness and hue. “Good” marking materials fully comply with ASTM 6628 and have no failures, “fair” materials have one or two failures for at least one or both attributes, and “poor” materials have three or more failed data points for one attribute or both. For example, a marking that has two lightness values and two hue values that fall outside the given limits receives a “fair” color performance rating.

White markings rarely fall outside the chromaticity limits, but in the NTPEP sample, a single point from the dataset did, most likely due to error. Epoxy on asphalt performed the worst in lightness for white

materials, but performed very well on concrete. Yellow materials for both epoxies and polyureas performed poorly on both pavement types. Thermoplastic materials remained robust, with the exception of a pair of white and yellow counterparts on concrete pavement from the Minnesota site.

Table 10. Pavement Marking Daytime Color Data Summary from Florida, Minnesota, and Pennsylvania Test Decks with Performance Rating
(Source: NTPEP Datamine)

NTPEP Code (State)	Material Type	COLOR	Asphalt						Concrete					
			Total # of Points	Count Y Failures	Age of First Y Failure (mo)	Count xy Failures	Age of First xy Failure (mo)	Color Rating	Total # of Points	Count Y Failures	Age of First Y Failure (mo)	Count xy Failures	Age of First xy Failure (mo)	Color Rating
PMM-2010-01-046 (MN)	Epoxy	Yellow	10	1	27	4	15	Poor	10	0		3	27	Poor
PMM-2010-01-047 (MN)	Epoxy	White	10	2	21	0		Fair	10	0		0		Good
PMM-2011-01-087 (PA)	Epoxy	White	11	5	5	0		Poor	11	0		0		Good
PMM-2011-01-088 (PA)	Epoxy	White	11	3	15	0		Poor	11	0		0		Good
PMM-2011-01-089 (PA)	Epoxy	Yellow	11	10	1	4	12	Poor	11	2	15	0		Fair
PMM-2011-01-092 (PA)	Epoxy	Yellow	11	9	5	2	12	Poor	11	4	15	0		Poor
PMM-2010-01-058 (MN)	Polyurea	White	10	1	27	0		Fair	10	0		0		Good
PMM-2010-01-059 (MN)	Polyurea	Yellow	10	9	3	6	15	Poor	10	2	12	3	24	Poor
PMM-2010-01-060 (MN)	Polyurea	White	10	1	27	0		Fair	10	0		0		Good
PMM-2010-01-061 (MN)	Polyurea	Yellow	10	5	15	5	21	Poor	10	1	27	1	27	Fair
PMM-2012-01-038 (FL)	Polyurea	White	13	4	18	0		Poor	13	6	15	0		Poor
PMM-2012-01-039 (FL)	Polyurea	Yellow	13	11	6	6	21	Poor	13	6	12	7	9	Poor
PMM-2010-01-040 (MN)	Thermoplastic	Yellow	10	1	3	0		Fair	10	7	12	7	12	Poor
PMM-2010-01-041 (MN)	Thermoplastic	White	10	0		0		Good	10	7	12	0		Poor
PMM-2011-01-047 (PA)	Thermoplastic	White	11	1	5	0		Fair	11	0		0		Good
PMM-2011-01-048 (PA)	Thermoplastic	Yellow	11	1	5	2	12	Fair	11	0		0		Good
PMM-2011-01-049 (PA)	Thermoplastic	White	11	0		0		Good	11	0		0		Good
PMM-2011-01-050 (PA)	Thermoplastic	Yellow	11	0		1	12	Fair	11	0		0		Good
PMM-2011-01-063 (PA)	Thermoplastic	Yellow	11	2	5	0		Fair	11	0		0		Good
PMM-2011-01-064 (PA)	Thermoplastic	Yellow	11	1	5	1	33	Fair	11	0		0		Good
PMM-2011-01-103 (PA)	Thermoplastic	White	11	2	11	0		Fair	11	0		0		Good
PMM-2011-01-104 (PA)	Thermoplastic	Yellow	11	0		1	36	Fair	9	0		0		Good
PMM-2011-01-105 (PA)	Thermoplastic	White	11	1	1	0		Fair	11	0		0		Good
PMM-2011-01-106 (PA)	Thermoplastic	Yellow	11	0		1	33	Fair	9	0		0		Good

Continued - Table 10. Daytime Color Data Summary with Performance Rating

NTPEP Code (State)	Material Type	COLOR	Asphalt						Concrete					
			Total # of Points	Count Y Failures	Age of First Y Failure (mo)	Count xy Failures	Age of First xy Failure (mo)	Color Rating	Total # of Points	Count Y Failures	Age of First Y Failure (mo)	Count xy Failures	Age of First xy Failure (mo)	Color Rating
PMM-2012-01-001 (FL)	Thermoplastic	White	13	0		1	9	Fair	13	0		0		Good
PMM-2012-01-002 (FL)	Thermoplastic	Yellow	13	0		0		Good	13	0		0		Good
PMM-2012-01-003 (FL)	Thermoplastic	White	13	0		0		Good	13	0		0		Good
PMM-2012-01-004 (FL)	Thermoplastic	Yellow	13	0		0		Good	13	0		0		Good
PMM-2012-01-019 (FL)	Thermoplastic	White	11	0		0		Good	11	0		0		Good
PMM-2012-01-022 (FL)	Thermoplastic	White	11	0		0		Good	11	0		0		Good
PMM-2012-01-024 (FL)	Thermoplastic	Yellow	11	0		0		Good	11	0		0		Good
PMM-2012-01-025 (FL)	Thermoplastic	Yellow	11	0		0		Good	11	0		0		Good
PMM-2012-01-031 (FL)	Thermoplastic	White	13	0		0		Good	13	0		0		Good
PMM-2012-01-032 (FL)	Thermoplastic	Yellow	13	2	3	0		Fair	13	1	15	0		Fair
PMM-2012-01-033 (FL)	Thermoplastic	Yellow	13	3	12	0		Poor	13	0		0		Good
PMM-2012-01-043 (FL)	Thermoplastic	White	13	0		0		Good	13	0		0		Good
PMM-2012-01-044 (FL)	Thermoplastic	Yellow	13	0		0		Good	13	0		0		Good
PMM-2012-01-045 (FL)	Thermoplastic	White	13	0		0		Good	13	0		0		Good
PMM-2012-01-046 (FL)	Thermoplastic	Yellow	13	1	15	0		Fair	13	0		0		Good
PMM-2012-01-053 (FL)	Thermoplastic	White	13	0		0		Good	13	0		0		Good
PMM-2012-01-054 (FL)	Thermoplastic	Yellow	13	0		0		Good	13	0		0		Good
PMM-2012-01-055 (FL)	Thermoplastic	White	13	0		0		Good	13	0		0		Good
PMM-2012-01-056 (FL)	Thermoplastic	Yellow	13	0		0		Good	13	0		0		Good
PMM-2010-01-006 (MN)	MMA	White	10	8	3	0		Poor	10	2	27	0		Fair
PMM-2010-01-007 (MN)	MMA	Yellow	10	7	3	2	15	Poor	10	7	3	6	12	Poor
PMM-2010-01-008 (MN)	MMA	White	10	0		0		Good	10	1	36	0		Fair
PMM-2010-01-009 (MN)	MMA	Yellow	10	3	15	3	24	Poor	10	7	12	7	12	Poor
PMM-2010-01-042 (MN)	MMA	Yellow	9	8	0	7	9	Poor	9	5	21	6	15	Poor

Continued - Table 10. Daytime Color Data Summary with Performance Rating

NTPEP Code (State)	Material Type	COLOR	Asphalt						Concrete					
			Total Points	Count Y Failures	Age of First Y Failure (mo)	Count xy Failures	Age of First xy Failure (mo)	Color Rating	Total Points	Count Y Failures	Age of First Y Failure (mo)	Count xy Failures	Age of First xy Failure (mo)	Color Rating
PMM-2010-01-043 (MN)	MMA	White	10	9	3	0		Poor	10	5	15	0		Poor
PMM-2011-01-065 (PA)	MMA	White	11	8	0	0		Poor	11	1	27	0		Fair
PMM-2011-01-066 (PA)	MMA	Yellow	11	11	0	7	11	Poor	11	6	0	8	0	Poor
PMM-2011-01-067 (PA)	MMA	White	11	2	15	0		Fair	11	0		0		Good
PMM-2011-01-068 (PA)	MMA	Yellow	11	1	27	3	15	Poor	11	0		2	15	Fair
PMM-2011-01-069 (PA)	MMA	White	11	6	5	0		Poor	11	3	12	0		Poor
PMM-2011-01-070 (PA)	MMA	Yellow	11	4	11	5	11	Poor	11	1	24	4	15	Poor
PMM-2011-01-071 (PA)	MMA	White	11	1	27	0		Fair	11	0		0		Good
PMM-2011-01-072 (PA)	MMA	Yellow	11	2	15	2	15	Poor	11	0		0		Good
PMM-2011-01-085 (PA)	MMA	White	11	8	0	0		Poor	11	3	1	0		Poor
PMM-2011-01-086 (PA)	MMA	Yellow	11	6	0	3	12	Poor	11	4	11	6	12	Poor
PMM-2012-01-082 (FL)	MMA	White	13	12	3	0		Poor	13	11	6	0		Poor
PMM-2012-01-083 (FL)	MMA	Yellow	13	13	0	5	21	Poor	13	12	3	10	6	Poor
PMM-2012-01-084 (FL)	MMA	White	13	9	12	0		Poor	13	6	21	0		Poor
PMM-2012-01-085 (FL)	MMA	Yellow	13	11	6	9	12	Poor	13	9	12	9	12	Poor
PMM-2010-01-044 (MN)	Urethane	Yellow	10	1	27	3	24	Poor	10	0		4	21	Poor
PMM-2010-01-045 (MN)	Urethane	White	10	0		0		Good	10	1	36	0		Fair
PMM-2010-01-062 (MN)	Urethane	White	10	1	27	1	33	Fair	10	1	33	0		Fair
PMM-2010-01-063 (MN)	Urethane	Yellow	10	4	15	1	33	Poor	10	1	27	2	33	Poor
PMM-2011-01-083 (PA)	Urethane	White	11	5	15	0		Poor	11	0		0		Good
PMM-2011-01-084 (PA)	Urethane	Yellow	11	6	5	7	12	Poor	11	0		1	36	Fair

Summary

Table 11 provides the definitions of performance ratings for all three performance metrics (retroreflectivity, durability, and color). Table 12 summarizes the calculated performance ratings of each marking material to provide a collective representation of the materials' performance. Marking materials that received a rating of "Good" in all categories for either pavement type are highlighted in yellow. As shown, one white epoxy, one white polyurea, and one white urethane marking material received a "Good" rating in all performance categories for a concrete surfaced roadway. Several white and yellow thermoplastic marking materials received a rating of "Good" in all categories for both asphalt and concrete roadways. However, none of the MMA marking materials received a "Good" rating in all categories for either asphalt or concrete surfaced roads.

Table 11. Pavement Marking Material Durability Performance Rating Definitions for This Study's Analysis

	Retroreflectivity (mcd/m^2/lux)						Durability Rating			Color Analysis		
	Speed < 70 MPH			Speed ≥ 70 MPH								
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
White	>250	250-150	<150	>250	250-175	<175	>7	6-7	<6	0 fails	<3 fails on at least one criterion	≥3 fails on one criterion
Yellow	>175	175-100	<100	>175	175-125	<125						

Table 12. Performance Rating Definition Summary for Durable Materials at 36 Months

NTPEP Code (State)	Material Type	Color	On Asphalt				On Concrete			
			Retroreflectivity Rating		Durability Rating	Color Rating	Retroreflectivity Rating		Durability Rating	Color Rating
			Speed < 70 MPH	Speed ≥ 70 MPH			Speed < 70 MPH	Speed ≥ 70 MPH		
PMM-2010-01-046 (MN)	Epoxy	Yellow	Fair	Fair	Fair	Poor	Fair	Fair	Poor	Poor
PMM-2010-01-047 (MN)	Epoxy	White	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Good
PMM-2011-01-087 (PA)	Epoxy	White	Fair	Fair	Good	Poor	Good	Good	Good	Good
PMM-2011-01-088 (PA)	Epoxy	White	Fair	Poor	Good	Poor	Fair	Fair	Good	Good
PMM-2011-01-089 (PA)	Epoxy	Yellow	Fair	Poor	Good	Poor	Fair	Fair	Good	Fair
PMM-2011-01-092 (PA)	Epoxy	Yellow	Fair	Fair	Good	Poor	Good	Good	Good	Poor
PMM-2010-01-058 (MN)	Polyurea	White	Fair	Fair	Fair	Fair	Fair	Fair	Good	Good
PMM-2010-01-059 (MN)	Polyurea	Yellow	Fail	Fail	Poor	Poor	Fail	Fail	Good	Poor
PMM-2010-01-060 (MN)	Polyurea	White	Fair	Fair	Fair	Fair	Good	Good	Good	Good
PMM-2010-01-061 (MN)	Polyurea	Yellow	Poor	Fail	Good	Poor	Poor	Fail	Good	Fair
PMM-2012-01-038 (FL)	Polyurea	White	Fair	Fair	Good	Poor	Good	Good	Good	Poor

NTPEP Code (State)	Material Type	Color	On Asphalt				On Concrete			
			Retroreflectivity Rating		Durability Rating	Color Rating	Retroreflectivity Rating		Durability Rating	Color Rating
			Speed < 70 MPH	Speed ≥ 70 MPH			Speed < 70 MPH	Speed ≥ 70 MPH		
PMM-2012-01-039 (FL)	Polyurea	Yellow	Fair	Fair	Good	Poor	Good	Good	Good	Poor
PMM-2010-01-040 (MN)	Thermoplastic	Yellow	Fair	Poor	Fair	Fair	Fail	Fail	Poor	Poor
PMM-2010-01-041 (MN)	Thermoplastic	White	Fair	Fair	Poor	Good	Fail	Fail	Poor	Poor
PMM-2011-01-047 (PA)	Thermoplastic	White	Fair	Fair	Good	Fair	Fair	Fair	Good	Good
PMM-2011-01-048 (PA)	Thermoplastic	Yellow	Poor	Fail	Good	Fair	Fair	Poor	Fair	Good
PMM-2011-01-049 (PA)	Thermoplastic	White	Fair	Fair	Fair	Good	Fair	Fair	Good	Good
PMM-2011-01-050 (PA)	Thermoplastic	Yellow	Poor	Fail	Fair	Fair	Fair	Poor	Good	Good
PMM-2011-01-063 (PA)	Thermoplastic	Yellow	Poor	Fail	Poor	Fair	Fair	Fair	Good	Good
PMM-2011-01-064 (PA)	Thermoplastic	Yellow	Fail	Fail	Poor	Fair	Fair	Poor	Good	Good
PMM-2011-01-103 (PA)	Thermoplastic	White	Good	Good	Good	Fair	Fair	Fair	Poor	Good
PMM-2011-01-104 (PA)	Thermoplastic	Yellow	Poor	Fail	Fair	Fair	Fail	Fail	Poor	Good
PMM-2011-01-105 (PA)	Thermoplastic	White	Fair	Fair	Fair	Fair	Fair	Fair	Poor	Good
PMM-2011-01-106 (PA)	Thermoplastic	Yellow	Poor	Fail	Fair	Fair	Fail	Fail	Poor	Good
PMM-2012-01-001 (FL)	Thermoplastic	White	Good	Good	Good	Fair	Good	Good	Good	Good
PMM-2012-01-002 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good	Good	Good	Good	Good
PMM-2012-01-003 (FL)	Thermoplastic	White	Good	Good	Good	Good	Good	Good	Good	Good
PMM-2012-01-004 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good	Good	Good	Good	Good
PMM-2012-01-019 (FL)	Thermoplastic	White	Good	Good	Good	Good	Good	Good	Poor	Good
PMM-2012-01-022 (FL)	Thermoplastic	White	Good	Good	Good	Good	Good	Good	Good	Good
PMM-2012-01-024 (FL)	Thermoplastic	Yellow	Fair	Fair	Good	Good	Poor	Fail	Poor	Good
PMM-2012-01-025 (FL)	Thermoplastic	Yellow	Fair	Fair	Good	Good	Fair	Poor	Poor	Good
PMM-2012-01-031 (FL)	Thermoplastic	White	Good	Good	Good	Good	Good	Good	Good	Good
PMM-2012-01-032 (FL)	Thermoplastic	Yellow	Good	Good	Good	Fair	Good	Good	Good	Fair
PMM-2012-01-033 (FL)	Thermoplastic	Yellow	Good	Good	Good	Poor	Good	Good	Good	Good

NTPEP Code (State)	Material Type	Color	On Asphalt				On Concrete			
			Retroreflectivity Rating		Durability Rating	Color Rating	Retroreflectivity Rating		Durability Rating	Color Rating
			Speed < 70 MPH	Speed ≥ 70 MPH			Speed < 70 MPH	Speed ≥ 70 MPH		
PMM-2012-01-043 (FL)	Thermoplastic	White	Fair	Fair	Good	Good	Good	Good	Good	Good
PMM-2012-01-044 (FL)	Thermoplastic	Yellow	Fair	Fair	Good	Good	Fair	Fair	Good	Good
PMM-2012-01-045 (FL)	Thermoplastic	White	Fair	Fair	Good	Good	Good	Good	Good	Good
PMM-2012-01-046 (FL)	Thermoplastic	Yellow	Good	Good	Good	Fair	Good	Good	Good	Good
PMM-2012-01-053 (FL)	Thermoplastic	White	Fair	Fair	Good	Good	Good	Good	Good	Good
PMM-2012-01-054 (FL)	Thermoplastic	Yellow	Fair	Fair	Good	Good	Fair	Fair	Good	Good
PMM-2012-01-055 (FL)	Thermoplastic	White	Fair	Fair	Good	Good	Good	Good	Good	Good
PMM-2012-01-056 (FL)	Thermoplastic	Yellow	Good	Good	Good	Good	Good	Good	Good	Good
PMM-2010-01-006 (MN)	MMA	White	Fair	Fair	Fair	Poor	Fair	Fair	Fair	Fair
PMM-2010-01-007 (MN)	MMA	Yellow	Fair	Fair	Fair	Poor	Fair	Poor	Fair	Poor
PMM-2010-01-008 (MN)	MMA	White	Fair	Fair	Fair	Good	Poor	Fail	Poor	Fair
PMM-2010-01-009 (MN)	MMA	Yellow	Poor	Fail	Good	Poor	Fail	Fail	Poor	Poor
PMM-2010-01-042 (MN)	MMA	Yellow	Fair	Fair	Poor	Poor	Poor	Fail	Poor	Poor
PMM-2010-01-043 (MN)	MMA	White	Good	Good	Poor	Poor	Good	Good	Poor	Poor
PMM-2011-01-065 (PA)	MMA	White	Poor	Poor	Poor	Poor	Fair	Fair	Poor	Fair
PMM-2011-01-066 (PA)	MMA	Yellow	Fair	Poor	Poor	Poor	Fair	Fair	Poor	Poor
PMM-2011-01-067 (PA)	MMA	White	Poor	Poor	Fair	Fair	Fair	Fair	Good	Good
PMM-2011-01-068 (PA)	MMA	Yellow	Fair	Poor	Fair	Poor	Fair	Fair	Good	Fair
PMM-2011-01-069 (PA)	MMA	White	Fair	Fair	Fair	Poor	Good	Good	Good	Poor
PMM-2011-01-070 (PA)	MMA	Yellow	Fair	Fair	Fair	Poor	Fair	Fair	Fair	Poor
PMM-2011-01-071 (PA)	MMA	White	Poor	Poor	Good	Fair	Poor	Poor	Good	Good
PMM-2011-01-072 (PA)	MMA	Yellow	Fair	Fail	Good	Poor	Poor	Fail	Good	Good
PMM-2011-01-085 (PA)	MMA	White	Poor	Poor	Fair	Poor	Poor	Poor	Poor	Poor
PMM-2011-01-086 (PA)	MMA	Yellow	Fair	Fair	Fair	Poor	Good	Good	Good	Poor

NTPEP Code (State)	Material Type	Color	On Asphalt				On Concrete			
			Retroreflectivity Rating		Durability Rating	Color Rating	Retroreflectivity Rating		Durability Rating	Color Rating
			Speed < 70 MPH	Speed ≥ 70 MPH			Speed < 70 MPH	Speed ≥ 70 MPH		
PMM-2012-01-082 (FL)	MMA	White	Fair	Poor	Good	Poor	Fair	Fair	Good	Poor
PMM-2012-01-083 (FL)	MMA	Yellow	Fair	Poor	Good	Poor	Fair	Fair	Good	Poor
PMM-2012-01-084 (FL)	MMA	White	Poor	Poor	Good	Poor	Good	Good	Good	Poor
PMM-2012-01-085 (FL)	MMA	Yellow	Poor	Fail	Good	Poor	Fair	Fair	Good	Poor
PMM-2010-01-044 (MN)	Urethane	Yellow	Fair	Fair	Fair	Poor	Fair	Fair	Fair	Poor
PMM-2010-01-045 (MN)	Urethane	White	Fair	Fair	Fair	Good	Fair	Fair	Fair	Fair
PMM-2010-01-062 (MN)	Urethane	White	Fair	Fair	Fair	Fair	Fair	Poor	Poor	Fair
PMM-2010-01-063 (MN)	Urethane	Yellow	Fair	Poor	Fair	Poor	Poor	Fail	Poor	Poor
PMM-2011-01-083 (PA)	Urethane	White	Fair	Fair	Good	Poor	Good	Good	Good	Good
PMM-2011-01-084 (PA)	Urethane	Yellow	Fair	Fair	Good	Poor	Good	Good	Good	Fair

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the multi-state survey and the NTPEP data analysis are summarized here. The four state DOTs (Colorado, New Mexico, Texas, and Utah) that participated in the survey are facing similar challenges to Arizona in pavement marking management. A few of the key methods they have used to increase material performance are listed below. The states using these methods are listed in parentheses.

- Recessing marking material in a groove extends marking service life (Colorado, New Mexico, Utah).
- Using thicker wet film thicknesses of paint and thermoplastic markings can increase marking performance (Texas).
- Using minimum initial retroreflectivity and/or initial durability specifications for durable markings sets a performance goal for material suppliers (New Mexico, Texas).
- Defining a minimum retroreflectivity for end of service life helps ensure roadways are restriped as needed (Colorado, Utah).

Of the 59 products from NTPEP test decks analyzed for this study, the thermoplastic markings on Florida test decks had the highest performance ratings at the end of the three-year evaluation period. None of the MMA marking materials received a "Good" rating in all performance categories (retroreflectivity, durability, and color) for either asphalt or concrete surfaced roads. One white epoxy, one white polyurea, and one white urethane marking material received a "Good" rating in all performance categories for a concrete surfaced roadway. However, 12 white and eight yellow thermoplastic marking materials on Florida test decks received a rating of "Good" in all categories. Of these 20 thermoplastic products, 13 were on concrete-surfaced roadways and seven were on asphalt-surfaced roadways. Therefore, thermoplastics in warmer climates with no snow removal will perform well on both concrete and asphalt roadways.

Recommendations are provided on the optimum marking types, and suggestions are made for improved ADOT marking performance. These recommendations and suggestions are based on the analysis results of the NTPEP data, the multi-state survey, and discussions with ADOT stakeholders.

OPTIMUM MARKING TYPES

Optimum marking materials are those that are compatible with a site, provide an appropriate service life, and are cost effective. To determine the optimum markings for ADOT from the NTPEP data, an end of service life must first be determined. To assess cost effectiveness, the different markings' equivalent annual uniform cost (EAUC) are calculated and compared.

Retroreflectivity was the metric used to determine the NTPEP markings' service life because it is the most common performance metric and the only performance metric being considered for a national standard. To simplify comparisons, only the white marking retroreflectivity performances were reviewed. As shown in the retroreflectivity performance curves in Figures 5 through 26, none of the white marking materials reached the 100 mcd/m^2/lux failure threshold by the end of the 36-month

evaluation period. Therefore, the retroreflectivity values for all materials of one type on the same pavement and in the same climate type (Cold: Minnesota and Pennsylvania, Warm: Florida) were averaged together and the future retroreflectivity values projected based on the current deterioration slope. The values were projected until the failure threshold was reached. Table 13 presents the service life values of the NTPEP data following these procedures.

Table 13. NTPEP Marking Service Lives (in Years) for Different Climates and Pavement Types

Marking Type	Climate Type			
	Cold (MN and PA)		Warm (FL)	
	Pavement Type		Pavement Type	
	Asphalt	Concrete	Asphalt	Concrete
Epoxy	4 yrs	4 yrs	N/A	N/A
Polyurea	5 yrs	5 yrs	5 yrs	6 yrs
Thermoplastic	6 yrs	5 yrs	8 yrs	7 yrs
Urethane	5 yrs	5 yrs	N/A	N/A
MMA	5.5 yrs	5.5 yrs	N/A	N/A

Next, the EAUC was calculated using the following equation:

$$EAUC = NPV / [(1-1/((1+r)^t))/r]$$

Where:

NPV = Net Present Value (current marking installed unit price)

r = discount rate

t = time (marking service life)

Since ADOT is currently using epoxy and thermoplastic markings, it provided epoxy and thermoplastic bid prices for 2016 through 2019. All marking unit prices were based on 4-inch lines and were installed costs, not material costs. The quantities for the bids varied considerably, and prices varied accordingly. Projects with lower quantities had higher unit prices, and projects with higher quantities had lower unit prices. A majority of the quantities were between one mile and 50 miles. So all bids for quantities less than one mile and more than 50 miles were not used. The average unit price for epoxy was $0.41/lf, and the average unit price for thermoplastic was $0.46/lf.

The unit prices for polyurea, urethane, and MMA were acquired from other state DOT's that had typical bid prices for 4-inch lines for these marking types. The markings used by the Illinois DOT included polyurea and urethane, and the DOT keeps record of average annual installed unit prices. In 2013, the unit prices for polyurea and urethane were $2.25/lf and $2.00/lf, respectively, but by 2018 competition had brought prices down to $1.46/lf and $1.09/lf, respectively. While the use of MMA has grown some in the past few years, determining an average unit price is still difficult. The Kansas DOT routinely uses

MMA on bridges and interchanges. The typical 2019 unit price for these bids were $3 to $3.50/lf but could be as high as $5/lf. An MMA unit rate of $3.50/lf was assumed for ADOT. A summary of the current, typical unit prices for a 4-inch wide line of each marking type is listed below:

Epoxy: $0.41/lf

Polyurea: $1.46/lf

Thermoplastic: $0.46/lf

Urethane: $1.09/lf

MMA: $3.50/lf

Using the service life values, unit prices, and a discount rate of 3 percent, the EUAC of each marking type by climate and pavement type was calculated and is presented in Table 14.

Table 14. Equivalent Uniform Annual Costs ($/lf) of 4-Inch Lines of NTPEP Markings

Marking Type	Unit Price (Per Linear Foot)	Climate Type			
		Cold (MN and PA)		Warm (FL)	
		Pavement Type		Pavement Type	
		Asphalt	Concrete	Asphalt	Concrete
Epoxy	$0.41	$0.11	$0.11	-	-
Polyurea	$1.46	$0.32	$0.32	$0.32	$0.27
Thermoplastic	$0.46	$0.08	$0.10	$0.07	$0.07
Urethane	$1.09	$0.24	$0.24	-	-
MMA	$3.50	$0.70	$0.70	-	-

Thermoplastic and epoxy have the lowest EAUCs, and thermoplastic also has the longest service life, which would make it the best return on investment. If the budget is available, both urethane and polyurea could possibly be used as well. MMA, however, didn't have a single marking product that had a rating of Good for all performance categories (as summarized in Table 12) and has a high EAUC; and therefore, MMA is not recommended for ADOT roadways.

RECOMMENDATIONS FOR IMPROVED MARKING PERFORMANCE

The following is a list of recommendations that would be promising for ADOT to consider:

- Recess markings into the pavement in areas with snowfall, specifically locations at elevations above 4,000 feet.
- Use thicker thermosplastic markings (100 mil thickness) on roadways with surface treatments, such as chip seals.

- Decrease the bead application rate (quantities) for epoxy markings in locations above 4,000 feet elevation.
- Continue to require 70 percent true spheres or higher in marking specifications. Small increases in percent roundness can provide large increases in retroreflectivity.

Whether continuing to use existing marking materials or starting the use of new marking types, recommendations can be made on practices to improve marking performance and extend the service lives. The first recommendation is to recess markings in pavement in areas with snowfall, which in Arizona tends to be locations at elevations above 4,000 feet. From the state DOT surveys, both Colorado and Utah reported that service lives are dependent on roadway elevation. CDOT indicated that service lives are half as long at the higher elevations with snow removal. Utah, Colorado, and New Mexico DOTs stated that recessing markings extends their service lives, and Utah reported that it doubles the marking's life. The Illinois DOT started recessing markings in 2013, and the unit price for cutting a marking groove was $0.75/lf. However, by 2018, the groove cut cost was down to $0.45/lf.

A second recommendation is to use thicker thermosplastic markings (100 mil thickness) on roadways with surface treatments, such as chip seals. The thicker marking is needed to fill the gaps between the small aggregates (chips) on the pavement surface. With the gaps filled, then the beads will have a more uniform surface to bond and therefore be more visible. This would help improve the short service lives (< 2 years) that ADOT is experiencing on chip seal roads. This recommendation is based on feedback provided by the Texas DOT.

Finally, after a review of ADOT's pavement markings specifications, the researchers recommend that ADOT decrease the bead application rate (quantities) for epoxy markings in locations above 4,000 feet. The current specifications require 26 lbs of beads per gallon of marking material. At a quantity this high, the beads are flooding the line and so close to one another that they are blocking vehicle headlights from properly reflecting off the beads. Quantities similar to other marking types and lower elevations, such as 8-12 lbs/gallon, would provide better bead distribution. Also, bead roundness has an important role in how reflective a marking is. Specifications often require 70 percent true spheres or higher, and small increases in percent roundness can provide large increases in retroreflectivity. ADOT pavement marking specifications have requirements ranging from 70 percent to 75 percent. These are good values, and ADOT could consider making the roundness requirement 75 percent for all marking types to see improved retroreflectivity.

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APPENDIX A: SURVEY OF NEIGHBORING STATES

Survey Questions for ADOT Neighboring States

Questions regarding marking material and placement

1. What pavement marking products does your state use and what products are on your state's Approved Products List for pavement markings?

   _____
   _____
   _____

   What are the acceptance criteria, lab tests, standards, or policies to which the products must adhere?

   _____
   _____
   _____

   What is each product's expected service life?

   _____
   _____
   _____

2. What are typical material and installation costs or typical installed costs for the marking products listed in Question #1? Please indicate the marking line widths and thicknesses associated with these costs.

   _____
   _____
   _____

3. Thermoplastic Pavement Markings

a. Do you use thermoplastic pavement markings? ___Yes ___No
(If Yes, continue to part b. If No, skip to Question #4.)

b. For thermoplastic pavement markings, do you use?:
Select one:
____ intermix glass beads
____ drop-on glass beads
____ both intermix and drop-on beads

c. Please select the types of reflective media you use for thermoplastic:
____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

What combinations of beads/reflective media do you use on thermoplastic?
_____
_____

d. Please rate your experience with glass beads achieving expected retroreflectance on thermoplastic:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on thermoplastic:
_____
_____
_____
_____

4. Epoxy Pavement Markings

a. Do you use epoxy pavement markings? ___Yes ___No

(If Yes, continue to part b. If No, skip to Question #5.)

b. For epoxy pavement markings, do you use?:

Select one:

____ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for epoxy:

____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

For double-drop applications, what combinations of beads/reflective media do you use on epoxy?

_____
_____

d. Please rate your experience with glass beads achieving expected retroreflectance on epoxy:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on epoxy:

_____
_____
_____
_____

5. Paint Pavement Markings

a. Do you use paint pavement markings? ___Yes ___No

(If Yes, continue to part b. If No, skip to Question #6.)

b. For paint pavement markings, do you use?:

Select one:

____ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for paint:

____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

For double-drop applications, what combinations of beads/reflective media do you use on paint?

_____
_____

d. Please rate your experience with glass beads achieving expected retroreflectance on paint:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on paint:

_____
_____
_____
_____

6. Recessed Markings

   a. Do you recess any of your pavement markings (i.e. place them in a shallow groove cut into the pavement)? ___Yes ___No
   (If Yes, please continue to part b. If No, skip to Question #7.)

   b. Where do you typically use recessed markings and why?

   _____
   _____
   _____
   _____

   c. What groove depth(s) do you use for different marking thicknesses?

   _____
   _____

   d. What results or benefits have you experienced from recessing markings?

   _____
   _____
   _____

   e. What are typical costs for cutting the groove? Please indicate the groove width.

   _____
   _____

7. What are your quality control practices and acceptance criteria for product installation (e.g. field measurements)?

   _____
   _____
   _____

8. Does your state have any equipment or application requirements (or specifications)?
   ___Yes ___ No

   If Yes, please describe:
   _____
   _____
   _____

Questions regarding climate and environmental factors

9. Does your state have any special requirements/guidelines on pavement marking selection that is dependent on pavement surface type (concrete, asphalt, or chip seal)?

   ___Yes ___No

   If Yes, please describe and include which marking types you've found to work well on the different pavement types:

   _____
   _____
   _____

   Does your state have any special requirements/guidelines on pavement marking selection that is dependent on temperature ranges or climate (i.e. snow-removal regions)?
   ___Yes ___No

   If Yes, please describe and include which marking types you've found to work well in the different environments:

   _____
   _____
   _____

10. Please rate your state's experience with pavement marking's ability to resist color changes (fading) in severe UV exposure:

    1----------2----------3----------4----------5----------6----------7
    Poor Average Excellent

    Please comment on the sources of your successes or failures with achieving resistance to color fading:

    _____
    _____
    _____

    Does your state have a color specification (e.g. a defined Color Space)?

    _____
    _____
    _____

Questions regarding marking management and performance-based specs

11. Does your state have a pavement marking management program (e.g., database of marking performance)? ___Yes ___No

12. What are your state's criteria for pavement marking end of service life (e.g. minimum retroreflectance or presence)?

    _____
    _____
    _____

    What is your state's restriping strategy?

    _____
    _____
    _____

13. Does your state have any experience with performance-based specifications for pavement markings? ___Yes ___No

    If Yes, how is marking performance assessed (visual vs. retroreflectance measurement or other methods) and what have been the results? If measurement is performed, please describe the type of equipment used (hand-held retroreflectometer, mobile retroreflectometer, or both):

    _____
    _____
    _____

14. Has your state collected pavement marking performance data? ___Yes ___No

    If Yes, could you share that data? ___Yes ___No

15. Does your state require a warranty period for pavement markings? ___Yes ___No

    If Yes, please list the product(s) and warranty period(s):

    _____
    _____

16. If you have any additional comments, please provide them here:

_____
_____
_____

17. Would you like to be contacted with the results of this study? ___Yes ___No

APPENDIX B: COMPLETED SURVEYS

Survey Questions for ADOT Neighboring States

Questions regarding marking material and placement

1. What pavement marking products does your state use and what products are on your state's Approved Products List for pavement markings?
   Hi-Build Paint, Modified Epoxy, Preform Plastic Tape, Preform Thermoplastic

   What are the acceptance criteria, lab tests, standards, or policies to which the products must adhere?
   Two year field evaluation compared next to an approved product in the category as a baseline along with a certified test report (CTR) from an independent lab showing the product meets our specifications provided by the manufacturer. If and used in the field contractor must provide a Certificate of Compliance from the manufacturer.

   What is each product's expected service life?
   Hi-Build Paint – 1 to 2 years, Modified Epoxy – 3 to 5 years, Preform Plastic Tape – 6 to 8 years, Preform Thermoplastic – 4 to 6 years. In high mountain areas cut everything in half.

2. What are typical material and installation costs or typical installed costs for the marking products listed in Question #1? Please indicate the marking line widths and thicknesses associated with these costs.
   Based on a 4 inch line and large quantities (10K gallons and greater). Hi-Build (24 mils) - $25/gal, Modified Epoxy (18 mils) - $55/gal, Preform Tape - $9.50/SF, Preform Thermoplastic - $9.00/SF

3. <u>Thermoplastic Pavement Markings</u>

   a. Do you use thermoplastic pavement markings? _X__Yes ___No

      (If Yes, continue to part b. If No, skip to Question #4.)

   b. For thermoplastic pavement markings, do you use?:

      Select one:

      _____ intermix glass beads
      _____ drop-on glass beads
      __X__ both intermix and drop-on beads

c. Please select the types of reflective media you use for thermoplastic:

__X__ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

What combinations of beads/reflective media do you use on thermoplastic?
Preform Thermoplastic uses Type 1 intermix topped with the Colorado Blend Glass beads when heated.

d. Please rate your experience with glass beads achieving expected retroreflectance on thermoplastic: 5.5

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on thermoplastic:

When applying the top coating of beads you need to load it up.

4. <u>Epoxy Pavement Markings</u>

a. Do you use epoxy pavement markings? _X__Yes ___No

(If Yes, continue to part b. If No, skip to Question #5.)

b. For epoxy pavement markings, do you use?:

Select one:

__X__ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for epoxy:

____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
__X__ Other reflective media – Colorado Epoxy Blend Specification

For double-drop applications, what combinations of beads/reflective media do you use on epoxy?

_____

_____

d. Please rate your experience with glass beads achieving expected retroreflectance on epoxy: 7

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on epoxy:

Field testing to determine what combination of beads and application rates work for Colorado and proper application.

5. Paint Pavement Markings

a. Do you use paint pavement markings? _X__Yes ___No

(If Yes, continue to part b. If No, skip to Question #6.)

b. For paint pavement markings, do you use?:

Select one:

__X__ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for paint:

____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
__X__ Other reflective media – Colorado Paint Blend Specification

For double-drop applications, what combinations of beads/reflective media do you use on paint?

_____

_____

d. Please rate your experience with glass beads achieving expected retroreflectance on paint: 6

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on paint:

Field testing to determine what combination of beads and application rates work for Colorado and proper application.

6. Recessed Markings

a. Do you recess any of your pavement markings (i.e. place them in a shallow groove cut into the pavement)? _X__Yes ___No

(If Yes, please continue to part b. If No, skip to Question #7.)

b. Where do you typically use recessed markings and why?

Everywhere we use modified epoxy, preform tape, and preform thermos to protect them from plowing. It does also help with traffic wear.

c. What groove depth(s) do you use for different marking thicknesses?

Epoxy – 40 mils, Preform Tape – 130 mils, Preform Thermo – 125 mils

d. What results or benefits have you experienced from recessing markings?

Longer service life mentioned in previous question.

e. What are typical costs for cutting the groove? Please indicate the groove width.

Epoxy - $0.50 - 0.60 per SF, Preform Tape – Included in the bid (we don't surface apply), Preform Thermoplastic - $0.50/SF

7. What are your quality control practices and acceptance criteria for product installation (e.g. field measurements)?
Follow our specs and standards. Epoxy has a minimum retro value.

8. Does your state have any equipment or application requirements (or specifications)? _X_Yes ___ No

If Yes, please describe:
Please see Section 627 of CDOT's Standard Specifications. Section 600

Modified Epoxy

Preformed Plastic

Questions regarding climate and environmental factors

9. Does your state have any special requirements/guidelines on pavement marking selection that is dependent on pavement surface type (concrete, asphalt, or chip seal)?
___Yes __X_No

   If Yes, please describe and include which marking types you've found to work well on the different pavement types:
   _____
   _____
   _____

   Does your state have any special requirements/guidelines on pavement marking selection that is dependent on temperature ranges or climate (i.e. snow-removal regions)?
   __Yes _X_No – Our entire state is a snow removal region

   If Yes, please describe and include which marking types you've found to work well in the different environments:

10. Please rate your state's experience with pavement marking's ability to resist color changes (fading) in severe UV exposure: 6

    1----------2----------3----------4----------5----------6----------7
    Poor Average Excellent

    Please comment on the sources of your successes or failures with achieving resistance to color fading:
    We developed our Modified Epoxy Specification

    Does your state have a color specification (e.g. a defined Color Space)?
    Yes for Yellow, White follows specified QUV values

Questions regarding marking management and performance-based specs

11. Does your state have a pavement marking management program (e.g., database of marking performance)? _X__Yes ___No

12. What are your state's criteria for pavement marking end of service life (e.g. minimum retroreflectance or presence)?
    If they fall below 80 mcd or are worn they are put into the next project.

    What is your state's restriping strategy?
    Sections of highway are scoped and then scheduled in our annual pavement marking projects using the predicted service life of the material used based on terrain and AADT.

13. Does your state have any experience with performance-based specifications for pavement markings? _X_Yes ___No

    If Yes, how is marking performance assessed (visual vs. retroreflectance measurement or other methods) and what have been the results? If measurement is performed, please describe the type of equipment used (hand-held retroreflectometer, mobile retroreflectometer, or both):
    Performance is assessed using an initial retroreflectivity requirement of 400 for White and 250 for Yellow using hand held or mobile reflectometer. The results are excellent. Our pavement markings are installed more consistently and perform much better.

14. Has your state collected pavement marking performance data? _X__Yes ___No

    If Yes, could you share that data? _X__Yes ___No

15. Does your state require a warranty period for pavement markings? ___Yes _X__No

    CDOT tried this about 13 years ago and found them not to be cost effective. Please see the attached report.

    If Yes, please list the product(s) and warranty period(s):

16. If you have any additional comments, please provide them here:
    Feel free to call me if you have any further questions or want to discuss our procedures and policies more in depth. Shane Chevalier 303-365-7337.

17. Would you like to be contacted with the results of this study? _X__Yes ___No

New Mexico Survey Response

Survey Questions for ADOT Neighboring States

Questions regarding marking material and placement

1. What pavement marking products does your state use and what products are on your state's Approved Products List for pavement markings?
   Primary is high build waterborne
   All other product are on our website, doing business, Approved Products List

   What are the acceptance criteria, lab tests, standards, or policies to which the products must adhere?
   Spec book is on our website 700's

   What is each product's expected service life?
   Varies

2. What are typical material and installation costs or typical installed costs for the marking products listed in Question #1? Please indicate the marking line widths and thicknesses associated with these costs.
   .09/LF 6" stripe

3. Thermoplastic Pavement Markings

a. Do you use thermoplastic pavement markings? _X__Yes ___No

(If Yes, continue to part b. If No, skip to Question #4.)

b. For thermoplastic pavement markings, do you use?:

Select one:

____ intermix glass beads
__X__ drop-on glass beads
____ both intermix and drop-on beads

c. Please select the types of reflective media you use for thermoplastic:

__X__ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

What combinations of beads/reflective media do you use on thermoplastic?
NM blend

d. Please rate your experience with glass beads achieving expected retroreflectance on thermoplastic:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on thermoplastic:

_____
_____
_____
_____

4. Epoxy Pavement Markings

a. Do you use epoxy pavement markings? _X__Yes ___No

(If Yes, continue to part b. If No, skip to Question #5.)

b. For epoxy pavement markings, do you use?:

Select one:

___X_ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for epoxy:

_X___ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

For double-drop applications, what combinations of beads/reflective media do you use on epoxy?
NM blend

d. Please rate your experience with glass beads achieving expected retroreflectance on epoxy:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on epoxy:

_____
_____
_____
_____

5. Paint Pavement Markings

a. Do you use paint pavement markings? _X__Yes ___No

(If Yes, continue to part b. If No, skip to Question #6.)

b. For paint pavement markings, do you use?:

Select one:

____ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
__X__ both single and double-drop

c. Please select the types of reflective media you use for paint:

__X__ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

For double-drop applications, what combinations of beads/reflective media do you use on paint?
NM blend

d. Please rate your experience with glass beads achieving expected retroreflectance on paint:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on paint:

_____
_____
_____
_____

6. Recessed Markings

   a. Do you recess any of your pavement markings (i.e. place them in a shallow groove cut into the pavement)? X___Yes ___No

      (If Yes, please continue to part b. If No, skip to Question #7.)

   b. Where do you typically use recessed markings and why?

      Interstates

   c. What groove depth(s) do you use for different marking thicknesses?
      depends on reflector

   d. What results or benefits have you experienced from recessing markings?

      Snow plow prevention.

   e. What are typical costs for cutting the groove? Please indicate the groove width.

      very expensive

7. What are your quality control practices and acceptance criteria for product installation (e.g. field measurements)?
   _____
   _____
   _____

8. Does your state have any equipment or application requirements (or specifications)?
   _X__Yes ___ No

   If Yes, please describe: See our specs and PA's
   _____
   _____

Questions regarding climate and environmental factors

9. Does your state have any special requirements/guidelines on pavement marking selection that is dependent on pavement surface type (concrete, asphalt, or chip seal)?
   ___Yes X___No

If Yes, please describe and include which marking types you've found to work well on the different pavement types:

_____

_____

_____

Does your state have any special requirements/guidelines on pavement marking selection that is dependent on temperature ranges or climate (i.e. snow-removal regions)?
_X__Yes ___No

If Yes, please describe and include which marking types you've found to work well in the different environments:
Water borne primarily where winter maintenance is prevalent. All others dependent on location and preference.

10. Please rate your state's experience with pavement marking's ability to resist color changes (fading) in severe UV exposure:

1----------2----------3----------4----------5----------6----------7
Poor Average Excellent

Please comment on the sources of your successes or failures with achieving resistance to color fading:

_____

_____

_____

Does your state have a color specification (e.g. a defined Color Space)?
Yes

Questions regarding marking management and performance-based specs

11. Does your state have a pavement marking management program (e.g., database of marking performance)? ___Yes _X__No

12. What are your state's criteria for pavement marking end of service life (e.g. minimum retroreflectance or presence)?

_____

_____

_____

What is your state's restriping strategy?
Based on funding

13. Does your state have any experience with performance-based specifications for pavement markings? ___Yes __X_No -Not really

    If Yes, how is marking performance assessed (visual vs. retroreflectance measurement or other methods) and what have been the results? If measurement is performed, please describe the type of equipment used (hand-held retroreflectometer, mobile retroreflectometer, or both):

    _____
    _____
    _____

14. Has your state collected pavement marking performance data? ___Yes _X__No

    If Yes, could you share that data? ___Yes ___No

15. Does your state require a warranty period for pavement markings? _X__Yes ___No

    If Yes, please list the product(s) and warranty period(s): 1 year

16. If you have any additional comments, please provide them here:

    _____
    _____
    _____

17. Would you like to be contacted with the results of this study? ___Yes ___No

Texas Survey Response

Survey Questions for ADOT Neighboring States

Questions regarding marking material and placement

1. What pavement marking products does your state use and what products are on your state's Approved Products List for pavement markings?

   Texas uses thermoplastic pavement markings (~75%), acrylic latex traffic paint (~23%), epoxy pavement markings (~1%) and prefabricated tape pavement markings (~1%). Epoxy and prefab tape are only used on our high-volume concrete roadways.

   What are the acceptance criteria, lab tests, standards, or policies to which the products must adhere?
   Thermoplastic PM must meet AASHTO M249 and other formulation requirements.

   http://ftp.dot.state.tx.us/pub/txdot-info/cst/DMS/8000_series/pdfs/8220.pdf

   Traffic Paint PM must meet TxDOT-specified formulation.

   http://ftp.dot.state.tx.us/pub/txdot-info/cst/DMS/8000_series/pdfs/8200.pdf

   Epoxy PM requires a 1-yr TxDOT test deck meeting the following minimum performance: White: 250 mcd/m2/lx, Yellow: 175 mcd/m2/lx

   http://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2014/spec/ss6038.pdf

   Prefab Tape PM must meet the following minimum performance on a 2-yr NTPEP test deck: White: 200 mcd/m2/lx, Yellow: 150 mcd/m2/lx

   http://ftp.dot.state.tx.us/pub/txdot-info/cst/DMS/8000_series/pdfs/8240.pdf

   What is each product's expected service life?
   Thermoplastic PM: 3-4 years
   Traffic Paint: 1-2 years
   Epoxy PM: 4-5 years
   Prefab Tape: 4-5 years

2. What are typical material and installation costs or typical installed costs for the marking products listed in Question #1? Please indicate the marking line widths and thicknesses associated with these costs.
   Thermoplastic PM: ~$0.27/lft – avg for all styles of linear markings
   Traffic Paint: ~$0.12/lft - avg for all styles of linear markings
   Epoxy PM: ~$0.86/lft – avg for linear markings
   Prefab Tape: ~$6.75/lft – avg for linear markings

3. Thermoplastic Pavement Markings

   a. Do you use thermoplastic pavement markings? _X__Yes ___No

      (If Yes, continue to part b. If No, skip to Question #4.)

   b. For thermoplastic pavement markings, do you use?:

      Select one:

      ____ intermix glass beads
      ____ drop-on glass beads
      __X__ both intermix and drop-on beads

   c. Please select the types of reflective media you use for thermoplastic:

      __X__ Type 1 Glass Beads
      __X__ Type 2 Glass Beads
      __X__ Type 3 Glass Beads
      ____ Type 4 Glass Beads
      ____ Other reflective media (e.g. reflective elements)

      What combinations of beads/reflective media do you use on thermoplastic?
      Type I for intermix, double-drop of Type II and Type III for drop-on

   d. Please rate your experience with glass beads achieving expected retroreflectance on thermoplastic:

      1----------2----------3----------4----------**5**----------6----------7 N/A
      Poor Average Excellent

   e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on thermoplastic:
      Achieving minimum retroreflectivity with thermoplastic PM is highly dependent on the amount of thermo (mil thickness) applied

4. Epoxy Pavement Markings

a. Do you use epoxy pavement markings? _X__Yes ___No

(If Yes, continue to part b. If No, skip to Question #5.)

b. For epoxy pavement markings, do you use?:

Select one:

____ single-drop (one type) of reflective media
__X__ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for epoxy:

__X_ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
__X_ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

For double-drop applications, what combinations of beads/reflective media do you use on epoxy?
Contractors choose to use a double-drop of regular Type I and Type IV beads for epoxy PM

d. Please rate your experience with glass beads achieving expected retroreflectance on epoxy:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on epoxy:
Generally do not have issues with retro on epoxy PM.

5. Paint Pavement Markings

a. Do you use paint pavement markings? _X__Yes ___No

(If Yes, continue to part b. If No, skip to Question #6.)

b. For paint pavement markings, do you use?:

Select one:

____ single-drop (one type) of reflective media
__X__ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for paint:

____ Type 1 Glass Beads
__X__ Type 2 Glass Beads
__X__ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

For double-drop applications, what combinations of beads/reflective media do you use on paint?
regular Type II and Type III

d. Please rate your experience with glass beads achieving expected retroreflectance on paint:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on paint:
the thicker you can apply the traffic paint the better

6. Recessed Markings

   a. Do you recess any of your pavement markings (i.e. place them in a shallow groove cut into the pavement)? ___Yes _X__No

      (If Yes, please continue to part b. If No, skip to Question #7.)

   b. Where do you typically use recessed markings and why?

      _____
      _____
      _____
      _____

   c. What groove depth(s) do you use for different marking thicknesses?

      _____
      _____

   d. What results or benefits have you experienced from recessing markings?

      _____
      _____
      _____

   e. What are typical costs for cutting the groove? Please indicate the groove width.

      _____
      _____

7. What are your quality control practices and acceptance criteria for product installation (e.g. field measurements)?
   Contractors must supply mobile retro data. TxDOT uses a third-party contract to conduct owner verification of the contractor data.

8. Does your state have any equipment or application requirements (or specifications)?
   _X__Yes ___ No

   If Yes, please describe:

   _____
   _____
   _____

Questions regarding climate and environmental factors

9. Does your state have any special requirements/guidelines on pavement marking selection that is dependent on pavement surface type (concrete, asphalt, or chip seal)?
___Yes _X__No

   If Yes, please describe and include which marking types you've found to work well on the different pavement types:

   _____
   _____
   _____

   Does your state have any special requirements/guidelines on pavement marking selection that is dependent on temperature ranges or climate (i.e. snow-removal regions)?
___Yes _X__No

   If Yes, please describe and include which marking types you've found to work well in the different environments:

   _____
   _____
   _____

10. Please rate your state's experience with pavement marking's ability to resist color changes (fading) in severe UV exposure:

    1----------2----------3----------4----------5----------6----------7
    Poor Average Excellent

    Please comment on the sources of your successes or failures with achieving resistance to color fading:

    _____
    _____
    _____

    Does your state have a color specification (e.g. a defined Color Space)?
    yes, for each marking material

Questions regarding marking management and performance-based specs

11. Does your state have a pavement marking management program (e.g., database of marking performance)? ___Yes _X__No

12. What are your state's criteria for pavement marking end of service life (e.g. minimum retroreflectance or presence)?
    when a driver cannot see more than 3 markings in from of vehicle at night

    What is your state's restriping strategy?
    each district uses different methodologies but generally markings are replaced on a schedule or identified via night-drive inspection, however some districts are measuring existing retro and using this information to prioritize

13. Does your state have any experience with performance-based specifications for pavement markings? _X__Yes ___No

    If Yes, how is marking performance assessed (visual vs. retroreflectance measurement or other methods) and what have been the results? If measurement is performed, please describe the type of equipment used (hand-held retroreflectometer, mobile retroreflectometer, or both):
    Retroreflectivity – requiring retro has greatly increased the performance of our markings

14. Has your state collected pavement marking performance data? _X__Yes ___No

    If Yes, could you share that data? ___Yes _X__No

    TxDOT collects retro data but the vast majority of this data are in the districts and not easily accessible.

15. Does your state require a warranty period for pavement markings? ___Yes _X__No

    If Yes, please list the product(s) and warranty period(s):

    TxDOT used to bid warranty projects, particularly for prefab tape, but we have moved away from this practice.

16. If you have any additional comments, please provide them here:
    _____
    _____
    _____

17. Would you like to be contacted with the results of this study? _X__Yes ___No

Utah Survey Response

Survey Questions for ADOT Neighboring States

Questions regarding marking material and placement

1. What pavement marking products does your state use and what products are on your state's Approved Products List for pavement markings?

Waterborne for long line and messages, preformed thermoplastic for messages, 3M 380 tape for longline. We don't use an APL.

What are the acceptance criteria, lab tests, standards, or policies to which the products must adhere?

Durable markings (tape and thermo) required a manufacturer's bonded warranty.
Waterborne paint suppliers are prequalified based on our standard spec.

What is each product's expected service life?

Waterborne paint-1 to 2 years
Preformed thermo messages-2 years
Recesssed 3M tape-6 years below 5500 feet in elevation
Recesssed 3M tape-4 years above 5500 feet in elevation

2. What are typical material and installation costs or typical installed costs for the marking products listed in Question #1? Please indicate the marking line widths and thicknesses associated with these costs.

4 in. 3M tape-$2.30/ft installed
Preformed thermoplastic messages-$175.00 ea. installed
Waterborne paint @22 mils-$22.00/gal=$0.11/ft

3. Thermoplastic Pavement Markings

a. Do you use thermoplastic pavement markings? __x_Yes ___No

Preformed for messages only. Not for long line.

(If Yes, continue to part b. If No, skip to Question #4.)

b. For thermoplastic pavement markings, do you use?:

Select one:

____ intermix glass beads
____ drop-on glass beads
____ both intermix and drop-on beads

c. Please select the types of reflective media you use for thermoplastic:

____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

What combinations of beads/reflective media do you use on thermoplastic?

_____
_____

d. Please rate your experience with glass beads achieving expected retroreflectance on thermoplastic:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on thermoplastic:

_____
_____
_____
_____

4. Epoxy Pavement Markings

a. Do you use epoxy pavement markings? ___Yes __x_No
(If Yes, continue to part b. If No, skip to Question #5.)

b. For epoxy pavement markings, do you use?:
Select one:

____ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for epoxy:

____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
____ Other reflective media (e.g. reflective elements)

For double-drop applications, what combinations of beads/reflective media do you use on epoxy?

_____
_____

d. Please rate your experience with glass beads achieving expected retroreflectance on epoxy:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on epoxy:

_____
_____
_____
_____

5. Paint Pavement Markings

a. Do you use paint pavement markings? _x__Yes ___No
(If Yes, continue to part b. If No, skip to Question #6.)

b. For paint pavement markings, do you use?:
Select one:

__x__ single-drop (one type) of reflective media
____ double-drop (two types) of reflective media
____ both single and double-drop

c. Please select the types of reflective media you use for paint:

____ Type 1 Glass Beads
____ Type 2 Glass Beads
____ Type 3 Glass Beads
____ Type 4 Glass Beads
__x__ Other reflective media (e.g. reflective elements) Utah blend

For double-drop applications, what combinations of beads/reflective media do you use on paint?

_____
_____

d. Please rate your experience with glass beads achieving expected retroreflectance on paint:
1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

e. Please comment on the sources of your successes or failures with achieving expected retroreflectance on paint:

Key is getting the right thickness and good bead distribution.

6. Recessed Markings

a. Do you recess any of your pavement markings (i.e. place them in a shallow groove cut into the pavement)? _x__Yes ___No
(If Yes, please continue to part b. If No, skip to Question #7.)

b. Where do you typically use recessed markings and why?

Anywhere tape is installed avoid plow damage

c. What groove depth(s) do you use for different marking thicknesses?

125 mils but always subject to manufacturer's recommendation.

d. What results or benefits have you experienced from recessing markings?

Last longer

e. What are typical costs for cutting the groove? Please indicate the groove width.

$.40/ft per 5 in. line

7. What are your quality control practices and acceptance criteria for product installation (e.g. field measurements)?

For waterborne paint we're starting to implement an optional retro measurement protocol for bead acceptance and it's worked well so far. Durable markings are subject to the manufacturer's control.

8. Does your state have any equipment or application requirements (or specifications)?
___Yes ___ No
If Yes, please describe:

Don't understand this question. For what? We have our own striping trucks.

Questions regarding climate and environmental factors

9. Does your state have any special requirements/guidelines on pavement marking selection that is dependent on pavement surface type (concrete, asphalt, or chip seal)?
_x__Yes ___No
If Yes, please describe and include which marking types you've found to work well on the different pavement types:

See our guide.

Does your state have any special requirements/guidelines on pavement marking selection that is dependent on temperature ranges or climate (i.e. snow-removal regions)?

No.

If Yes, please describe and include which marking types you've found to work well in the different environments:
_____
_____
_____

10. Please rate your state's experience with pavement marking's ability to resist color changes (fading) in severe UV exposure:

1----------2----------3----------4----------5----------6----------7 N/A
Poor Average Excellent

Please comment on the sources of your successes or failures with achieving resistance to color fading:

White epoxy, where used on limited basis, turns grey

Does your state have a color specification (e.g. a defined Color Space)?

No

Questions regarding marking management and performance-based specs

11. Does your state have a pavement marking management program (e.g., database of marking performance)? ___Yes _x__No

12. What are your state's criteria for pavement marking end of service life (e.g. minimum retroreflectance or presence)?

150 mcd

What is your state's restriping strategy?

waterborne-1 to 2 years
durables-at end of service life

13. Does your state have any experience with performance-based specifications for pavement markings? _x__Yes ___No

If Yes, how is marking performance assessed (visual vs. retroreflectance measurement or other methods) and what have been the results? If measurement is performed, please describe the type of equipment used (hand-held retroreflectometer, mobile retroreflectometer, or both):

mobile retros and it's has worked pretty well. supplier has taken care of it.

14. Has your state collected pavement marking performance data? ___Yes __x_No
If Yes, could you share that data? ___Yes ___No

15. Does your state require a warranty period for pavement markings? _x__Yes ___No
If Yes, please list the product(s) and warranty period(s):

See our spec.

16. If you have any additional comments, please provide them here:
_____
_____
_____

17. Would you like to be contacted with the results of this study? _x__Yes ___No

APPENDIX C: NTPEP PAVEMENT MARKING CODES AND PRODUCT NAMES

Table 15. NTPEP Codes with Material Product Name

NTPEP Number	Product Name	Manufacturer	Site Name	Material Type	Color
PMM-2010-01-006	MMA Pathfinder	Aexcel Corporation	Minnesota (2010)	Methyl Methacrylate(MMA)	White
PMM-2010-01-007	MMA Pathfinder	Aexcel Corporation	Minnesota (2010)	Methyl Methacrylate(MMA)	Yellow
PMM-2010-01-008	White 98:2 Spray MMA	Aexcel Corporation	Minnesota (2010)	Methyl Methacrylate(MMA)	White
PMM-2010-01-009	Yellow 98:2 Spray MMA	Aexcel Corporation	Minnesota (2010)	Methyl Methacrylate(MMA)	Yellow
PMM-2010-01-040	998801	Ennis Paint Co.	Minnesota (2010)	Thermoplastic	Yellow
PMM-2010-01-041	998802	Ennis Paint Co.	Minnesota (2010)	Thermoplastic	White
PMM-2010-01-042	999906	Ennis Paint Co.	Minnesota (2010)	Methyl Methacrylate(MMA)	Yellow
PMM-2010-01-043	999905	Ennis Paint Co.	Minnesota (2010)	Methyl Methacrylate(MMA)	White
PMM-2010-01-044	999904	Ennis Paint Co.	Minnesota (2010)	Urethane	Yellow
PMM-2010-01-045	999903	Ennis Paint Co.	Minnesota (2010)	Urethane	White
PMM-2010-01-046	999902	Ennis Paint Co.	Minnesota (2010)	Epoxy	Yellow
PMM-2010-01-047	999901	Ennis Paint Co.	Minnesota (2010)	Epoxy	White
PMM-2010-01-058	POLY-CARB MARK-75.3 White	POLY-CARB	Minnesota (2010)	Polyurea	White
PMM-2010-01-059	POLY-CARB MARK-75.3 NL Yellow	POLY-CARB	Minnesota (2010)	Polyurea	Yellow
PMM-2010-01-060	POLY-CARB MARK-75.4 White	POLY-CARB	Minnesota (2010)	Polyurea	White
PMM-2010-01-061	POLY-CARB MARK-75.4 NL Yellow	POLY-CARB	Minnesota (2010)	Polyurea	Yellow
PMM-2010-01-062	POLY-CARB MARK-65.5 White	POLY-CARB	Minnesota (2010)	Urethane	White
PMM-2010-01-063	POLY-CARB MARK-65.5 NL Yellow	POLY-CARB	Minnesota (2010)	Urethane	Yellow
PMM-2011-01-047	ThermoDrop Performance White Alkyd Thermoplastic	Southern Synergy	Pennsylvania (2011)	Thermoplastic	White
PMM-2011-01-048	ThermoDrop Performance Lead-Free Yellow Alkyd Thermoplastic	Southern Synergy	Pennsylvania (2011)	Thermoplastic	Yellow
PMM-2011-01-049	ThermoDrop White Alkyd Thermoplastic	Southern Synergy	Pennsylvania (2011)	Thermoplastic	White
PMM-2011-01-050	ThermoDrop Lead-Free Yellow Alkyd Thermoplastic	Southern Synergy	Pennsylvania (2011)	Thermoplastic	Yellow
PMM-2011-01-063	PA2011-13	Ennis Paint Co.	Pennsylvania (2011)	Thermoplastic	Yellow
PMM-2011-01-064	PA2011-14	Ennis Paint Co.	Pennsylvania (2011)	Thermoplastic	Yellow
PMM-2011-01-065	PA2011-15	Ennis Paint Co.	Pennsylvania (2011)	Methyl Methacrylate(MMA)	White
PMM-2011-01-066	PA2011-16	Ennis Paint Co.	Pennsylvania (2011)	Methyl Methacrylate(MMA)	Yellow
PMM-2011-01-067	EVSP-11-1	Evonik	Pennsylvania (2011)	Methyl Methacrylate(MMA)	White
PMM-2011-01-068	EVSP-11-2	Evonik	Pennsylvania (2011)	Methyl Methacrylate(MMA)	Yellow
PMM-2011-01-069	EVPF-11-1	Evonik	Pennsylvania (2011)	Methyl Methacrylate(MMA)	White
PMM-2011-01-070	EVPF-11-2	Evonik	Pennsylvania (2011)	Methyl Methacrylate(MMA)	Yellow
PMM-2011-01-071	EVEX-11-1	Evonik	Pennsylvania (2011)	Methyl Methacrylate(MMA)	White
PMM-2011-01-072	EVEX-11-2	Evonik	Pennsylvania (2011)	Methyl Methacrylate(MMA)	Yellow
PMM-2011-01-083	Swarco/CPC MFUA -10 Dual Component	Swarco Colorado Paint Company	Pennsylvania (2011)	Urethane	White
PMM-2011-01-084	Swarco/CPC MFUA -10 Dual Component	Swarco Colorado Paint Company	Pennsylvania (2011)	Urethane	Yellow
PMM-2011-01-085	Swarco/CPC Swarcoplast Structured MMA	Swarco Colorado Paint Company	Pennsylvania (2011)	Methyl Methacrylate(MMA)	White
PMM-2011-01-086	Swarco/CPC Swarcoplast Structured MMA	Swarco Colorado Paint Company	Pennsylvania (2011)	Methyl Methacrylate(MMA)	Yellow
PMM-2011-01-087	MARK-55.9 White	POLY-CARB	Pennsylvania (2011)	Epoxy	White
PMM-2011-01-088	Mark-55.3	POLY-CARB	Pennsylvania (2011)	Epoxy	White
PMM-2011-01-089	Mark-55.3	POLY-CARB	Pennsylvania (2011)	Epoxy	Yellow

NTPEP Number	Product Name	Manufacturer	Site Name	Material Type	Color
PMM-2011-01-092	MARK-55.9 Non-Lead Yellow	POLY-CARB	Pennsylvania (2011)	Epoxy	Yellow
PMM-2011-01-103	Sherwin-Williams T11W1	Sherwin-Williams Company	Pennsylvania (2011)	Thermoplastic	White
PMM-2011-01-104	Sherwin Williams T11Y1	Sherwin-Williams Company	Pennsylvania (2011)	Thermoplastic	Yellow
PMM-2011-01-105	Sherwin-Williams T11W2	Sherwin-Williams Company	Pennsylvania (2011)	Thermoplastic	White
PMM-2011-01-106	Sherwin-Williams T11Y2	Sherwin-Williams Company	Pennsylvania (2011)	Thermoplastic	Yellow
PMM-2012-01-001	DIJ Alkyd Thermoplastic	DIJ Construction	Florida (2012)	Thermoplastic	White
PMM-2012-01-002	DIJ Alkyd Yellow Thermoplastic	DIJ Construction	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-003	DIJ White AASHTO Thermoplastic	DIJ Construction	Florida (2012)	Thermoplastic	White
PMM-2012-01-004	DIJ AASHTO YELLOW ALKYD THERMOPLASTIC	DIJ Construction	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-019	Sherwin-Williams T12W1	Sherwin-Williams Company	Florida (2012)	Thermoplastic	White
PMM-2012-01-022	Sherwin-Williams T12W2	Sherwin-Williams Company	Florida (2012)	Thermoplastic	White
PMM-2012-01-024	Sherwin-Williams T12Y2	Sherwin-Williams Company	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-025	Sherwin-Williams T12Y1	Sherwin-Williams Company	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-031	FL2012-05	Ennis Paint Co.	Florida (2012)	Thermoplastic	White
PMM-2012-01-032	FL2012-06	Ennis Paint Co.	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-033	FL2012-07	Ennis Paint Co.	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-038	3M Liquid Pavement Marking Series 5000	3M	Florida (2012)	Polyurea	White
PMM-2012-01-039	3M Liquid Pavement Marking Series 5001	3M	Florida (2012)	Polyurea	Yellow
PMM-2012-01-043	Thermo-Drop White Alkyd Thermoplastic	Southern Synergy	Florida (2012)	Thermoplastic	White
PMM-2012-01-044	Thermo-Drop Lead-Free Yellow Alkyd Thermoplastic	Southern Synergy	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-045	Thermo-Drop Performance White Alkyd Thermoplastic	Southern Synergy	Florida (2012)	Thermoplastic	White
PMM-2012-01-046	Thermo-Drop Performance Lead-Free Alkyd Thermoplastic	Southern Synergy	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-053	Ozark Materials, LLC White AASHTO Thermoplastic	Ozark Materials, LLC	Florida (2012)	Thermoplastic	White
PMM-2012-01-054	Ozark Materials, LLC Lead-Free Yellow AASHTO Thermoplastic	Ozark Materials, LLC	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-055	Ozark Materials, LLC Performance White Thermoplastic	Ozark Materials, LLC	Florida (2012)	Thermoplastic	White
PMM-2012-01-056	Ozark Materials, LLC Performance Lead-Free Yellow Thermoplastic	Ozark Materials, LLC	Florida (2012)	Thermoplastic	Yellow
PMM-2012-01-082	Sherwin-Williams M12W1	Sherwin-Williams Company	Florida (2012)	Methyl Methacrylate(MMA)	White
PMM-2012-01-083	Sherwin-Williams M12Y1	Sherwin-Williams Company	Florida (2012)	Methyl Methacrylate(MMA)	Yellow
PMM-2012-01-084	Sherwin-Williams M12W2	Sherwin-Williams Company	Florida (2012)	Methyl Methacrylate(MMA)	White
PMM-2012-01-085	Sherwin-Williams M12Y2	Sherwin-Williams Company	Florida (2012)	Methyl Methacrylate(MMA)	Yellow

APPENDIX D: NTPEP PAVEMENT MARKING PRODUCTS' BEAD INFORMATION

Table 16. NTPEP Pavement Marking Product's Bead Information

NTPEP Number	Product Type	Color	Bead Coating Type	Bead #1		Bead #2		Intermix Product %	Gradation
				Application Rate	Type	Application Rate	Type		
PMM-2010-01-006	MMA	White	Adhesion Promoting	12 lbs/gal	AASHTO M247 Type 5				AASHTO M247 Type 5
PMM-2010-01-007	MMA	Yellow	Adhesion Promoting	12 lbs/gal	AASHTO M247 Type 5				AASHTO M247 Type 5
PMM-2010-01-008	MMA	White	Adhesion Promoting	10 lbs/gal	AASHTO M247 Type 1				AASHTO M247 Type 1
PMM-2010-01-009	MMA	Yellow	Adhesion Promoting	10 lbs/gal	AASHTO M247 Type 5				AASHTO M247 Type 1
PMM-2010-01-040	Thermoplastic	Yellow	Uncoated	6.0	AASHTO M247 Type 1			40.0	AASHTO M247 Type 0
PMM-2010-01-041	Thermoplastic	White	Uncoated	6.0	AASHTO M247 Type 1			40.0	AASHTO M247 Type 0
PMM-2010-01-042	MMA	Yellow	Uncoated	16.0	AASHTO M247 Type 1				AASHTO M247 Type 0
PMM-2010-01-043	MMA	White	Uncoated	16.0	AASHTO M247 Type 1				AASHTO M247 Type 0
PMM-2010-01-044	Urethane	Yellow	Uncoated	8.0	Clusterbeads	8.0	AASHTO M247 Type 1		AASHTO M247 Type 0
PMM-2010-01-045	Urethane	White	Uncoated	8.0	Clusterbeads	8.0	AASHTO M247 Type 1		AASHTO M247 Type 0
PMM-2010-01-046	Epoxy	Yellow	Uncoated	8.0	Clusterbeads	8.0	AASHTO M247 Type 1		AASHTO M247 Type 0
PMM-2010-01-047	Epoxy	White	Uncoated	8.0	Clusterbeads	8.0	AASHTO M247 Type 1		AASHTO M247 Type 0
PMM-2010-01-058	Polyurea	White	Moisture Proof	12	AASHTO M247 Type 1	12	AASHTO M247 Type 3		AASHTO M247 Type 1
PMM-2010-01-059	Polyurea	Yellow	Moisture Proof	12	AASHTO M247 Type 1	12	AASHTO M247 Type 3		AASHTO M247 Type 1
PMM-2010-01-060	Polyurea	White	Moisture Proof	12	AASHTO M247 Type 1	12	AASHTO M247 Type 3		AASHTO M247 Type 1
PMM-2010-01-061	Polyurea	Yellow	Uncoated	12	AASHTO M247 Type 1	12	AASHTO M247 Type 3		AASHTO M247 Type 0
PMM-2010-01-062	Urethane	White	Uncoated	12	AASHTO M247 Type 1	12	AASHTO M247 Type 3		AASHTO M247 Type 1
PMM-2010-01-063	Urethane	Yellow	Moisture Proof	12	AASHTO M247 Type 1	12	AASHTO M247 Type 3		AASHTO M247 Type 1
PMM-2011-01-047	Thermoplastic	White	Uncoated	10-12 #/100ft2	AASHTO M247 Type 4	6-8 #/100ft2	AASHTO M247 Type 1	30	AASHTO M247 Type 1
PMM-2011-01-048	Thermoplastic	Yellow	Uncoated	10-12 #/100ft2	AASHTO M247 Type 4	6-8 #/100ft2	AASHTO M247 Type 1	30	AASHTO M247 Type 1
PMM-2011-01-049	Thermoplastic	White	Uncoated	Flood	AASHTO M247 Type 1			30	AASHTO M247 Type 1
PMM-2011-01-050	Thermoplastic	Yellow	Uncoated	Flood	AASHTO M247 Type 1			30	AASHTO M247 Type 1
PMM-2011-01-063	Thermoplastic	Yellow	Uncoated	4.0	AASHTO M247 Type 1	8.0	AASHTO M247 Type 3	32	AASHTO M247 Type 1
PMM-2011-01-064	Thermoplastic	Yellow	Uncoated	8.0	AASHTO M247 Type 3		AASHTO M247 Type 0	32	AASHTO M247 Type 1
PMM-2011-01-065	MMA	White	Multi Coating	8.0	AASHTO M247 Type 0				AASHTO M247 Type 1
PMM-2011-01-066	MMA	Yellow	Multi Coating	8.0	AASHTO M247 Type 1				AASHTO M247 Type 1
PMM-2011-01-067	MMA	White	Adhesion Promoting	6-8 lbs 100 sq/ft	AASHTO M247 Type 0				Other
PMM-2011-01-068	MMA	Yellow	Adhesion Promoting	6-8 Lbs/100 sq/ft	AASHTO M247 Type 0				Other
PMM-2011-01-069	MMA	White	Adhesion Promoting	6-8 lbs/100 sq/ft	AASHTO M247 Type 0				Other
PMM-2011-01-070	MMA	Yellow	Adhesion Promoting	6-8 lbs/ 100sq/ft	AASHTO M247 Type 0				Other
PMM-2011-01-071	MMA	White	Adhesion Promoting	6-8 Lbs/100 sq/ft	AASHTO M247 Type 0				Other
PMM-2011-01-072	MMA	Yellow	Adhesion Promoting	6-8 lbs/100 sq/ft	AASHTO M247 Type 0				Other
PMM-2011-01-083	Urethane	White	Multi Coating		50% Type 1 / 50% Type 4		50% Type 1 / 50% Type 4		Other
PMM-2011-01-084	Urethane	Yellow	Multi Coating		50% Type 1 / 50% Type 5		50% Type 1 / 50% Type 5		Other
PMM-2011-01-085	MMA	White	Uncoated	10#/100 sq. ft.	Megalux / Duralux				Other
PMM-2011-01-086	MMA	Yellow	Uncoated	10# / 100 sq.ft.	Other				Other
PMM-2011-01-087	Epoxy	White	Moisture Proof	12 pounds per gallon	AASHTO M247 Type 1	12-lbs per gallon	AASHTO M247 Type 4		AASHTO M247 Type 1
PMM-2011-01-088	Epoxy	White	Moisture Proof	12-lbs per gallon	AASHTO M247 Type 1	12-lbs per gallon	AASHTO M247 Type 4		AASHTO M247 Type 1
PMM-2011-01-089	Epoxy	Yellow	Moisture Proof		AASHTO M247 Type 1		AASHTO M247 Type 4		AASHTO M247 Type 1
PMM-2011-01-092	Epoxy	Yellow	Moisture Proof	12 pounds p/gln	AASHTO M247 Type 1	12	AASHTO M247 Type 4		AASHTO M247 Type 1
PMM-2011-01-103	Thermoplastic	White	Uncoated	10 lbs per 100 sq ft	AASHTO M247 Type 1			40%	AASHTO M247 Type 0
PMM-2011-01-104	Thermoplastic	Yellow	Uncoated	10 lbs per 100 sq ft	AASHTO M247 Type 1			40	AASHTO M247 Type 1

NTPEP Number	Product Type	Color	Bead Coating Type	Bead #1		Bead #2		Intermix	Gradation
PMM-2011-01-105	Thermoplastic	White	Uncoated	10# per 100 sq ft	AASHTO M247 Type 1	6# per 100 sq ft	AASHTO M247 Type 3	40%	AASHTO M247 Type 1
PMM-2011-01-106	Thermoplastic	Yellow	Uncoated	10# per 100 sq ft	AASHTO M247 Type 1	6# per 100 sq ft	AASHTO M247 Type 3	40	AASHTO M247 Type 1
PMM-2012-01-001	Thermoplastic	White	Uncoated	5 pounds per 100 SF	AASHTO M247 Type 2	5 Pounds per 100 SF	AASHTO M247 Type 3	30%	AASHTO M247 Type 1
PMM-2012-01-002	Thermoplastic	Yellow	Uncoated	5 pounds per 100 SF	AASHTO M247 Type 2	5 Pounds per 100 SF	AASHTO M247 Type 3	30%	AASHTO M247 Type 1
PMM-2012-01-003	Thermoplastic	White	Uncoated	5 pounds per 100 SF	AASHTO M247 Type 2	5 Pounds per 100 SF	AASHTO M247 Type 3	30	AASHTO M247 Type 1
PMM-2012-01-004	Thermoplastic	Yellow	Uncoated	5 pounds per 100 SF	AASHTO M247 Type 2	5 Pounds per 100 SF	AASHTO M247 Type 3	30	AASHTO M247 Type 1
PMM-2012-01-019	Thermoplastic	White	Uncoated	10#/100 sq ft	AASHTO M247 Type 1	6#/100sq ft	AASHTO M247 Type 3	40	AASHTO M247 Type 1
PMM-2012-01-022	Thermoplastic	White	Uncoated	10#/100 sq ft	AASHTO M247 Type 1	6#/100 sq ft	AASHTO M247 Type 3	40	AASHTO M247 Type 1
PMM-2012-01-024	Thermoplastic	Yellow	Uncoated	10#/100 sq ft	AASHTO M247 Type 1	6#/100 sq ft	AASHTO M247 Type 3	40	AASHTO M247 Type 1
PMM-2012-01-025	Thermoplastic	Yellow	Uncoated	10#/100 sq ft	AASHTO M247 Type 1	6#/100 sq ft	AASHTO M247 Type 3	40	AASHTO M247 Type 1
PMM-2012-01-031	Thermoplastic	White	Uncoated	8	AASHTO M247 Type 1			30	AASHTO M247 Type 1
PMM-2012-01-032	Thermoplastic	Yellow	Uncoated	8.0	AASHTO M247 Type 1			30	AASHTO M247 Type 1
PMM-2012-01-033	Thermoplastic	Yellow	Uncoated	8	AASHTO M247 Type 1			30	AASHTO M247 Type 1
PMM-2012-01-038	Polyurea	White	Uncoated	6.4 lbs/gallon	Utah Bead Blend				AASHTO M247 Type 0
PMM-2012-01-039	Polyurea	Yellow	Uncoated	6.4 lbs/gallon	Utah Bead Blend				AASHTO M247 Type 0
PMM-2012-01-043	Thermoplastic	White	Uncoated	flood	AASHTO M247 Type 1			35	AASHTO M247 Type 1
PMM-2012-01-044	Thermoplastic	Yellow	Uncoated	flood	AASHTO M247 Type 1			35	AASHTO M247 Type 1
PMM-2012-01-045	Thermoplastic	White	Uncoated	12	AASHTO M247 Type 4	10	AASHTO M247 Type 1	35	50/50 Type III/Type 1 Intermix
PMM-2012-01-046	Thermoplastic	Yellow	Uncoated	12	AASHTO M247 Type 4	10	AASHTO M247 Type 1	35	50/50 Type III/Type 1 Intermix
PMM-2012-01-053	Thermoplastic	White	Uncoated	flood	AASHTO M247 Type 1			30	AASHTO M247 Type 1
PMM-2012-01-054	Thermoplastic	Yellow	Uncoated	flood	AASHTO M247 Type 1			30	AASHTO M247 Type 1
PMM-2012-01-055	Thermoplastic	White	Uncoated	8	AASHTO M247 Type 1	12	AASHTO M247 Type 4	35	Type 1/Type 3 50/50 Intermix
PMM-2012-01-056	Thermoplastic	Yellow	Uncoated	8	AASHTO M247 Type 1	12	AASHTO M247 Type 4	35	Type 1/Type 3 50/50 Intermix
PMM-2012-01-082	MMA	White	Uncoated	12#/sq ft	Megalux 30/50				AASHTO M247 Type 1
PMM-2012-01-083	MMA	Yellow	Uncoated	12#/sq ft	Megalux 30/50				AASHTO M247 Type 1
PMM-2012-01-084	MMA	White	Uncoated	12#/sq ft	Megalux 30/50 - No Intermix				AASHTO M247 Type 1
PMM-2012-01-085	MMA	Yellow	Uncoated	12#/sq ft	Megalux 30/50 - No Intermix				AASHTO M247 Type 1