TRANSPORTATION LEARNING NETWORK

A partnership with MDT•NDDOT•SDDOT•WYDOT and the Mountain-Plains Consortium Universities

Welcome!

Optimization of Pavement Marking Performance

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Optimization of Pavement Marking Performance

(MPC 17-341)

Allen Jones, PE, PhD

Professor of Civil Engineering

South Dakota State University

Presentation Outline

- Background
- Objectives
- Field Data
  - Parameters and marking combinations
  - Test sites and field measurements
- Data Analysis
  - Performance evaluation
  - Cost analysis
- Conclusions
- Recommendations and Implementation

Background

- Thank You
  - Project Sponsors
    - Mountain Plains Consortium
    - South Dakota Department of Transportation
    - South Dakota State University
  - Student Researchers
    - Thomas Druyvestein → SDDOT, Road Design
    - Kofi Oppong → Iowa State University, PhD
  - Project Investigator
    - Dr. Nadim Wehbe, PhD, PE

Background

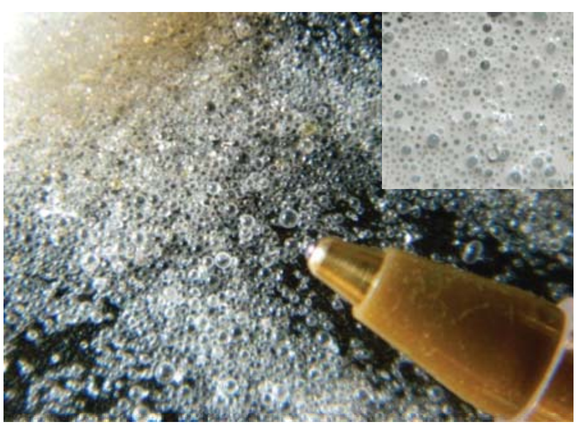
- Allen Jones
  - BS & MS – University of Idaho (1986, 1988)
  - PhD – University of Washington (2003)
  - Senior Engineer – Hart Crowser, Inc. (1988 – 2003)
  - Professor of Civil Engineering – South Dakota State University (2003- Present)
  - https://www.sdstate.edu/directory/allen-jones

Background

Pavement Markings

- Safety
  - Convey Information to the Driver
    - Channel or Guide Traffic Flow
    - Traffic Separation
- Adequately Visible
  - Day
  - Night
  - Adverse Weather

Background



Glass Spheres (Beads)

Wet Reflective Elements

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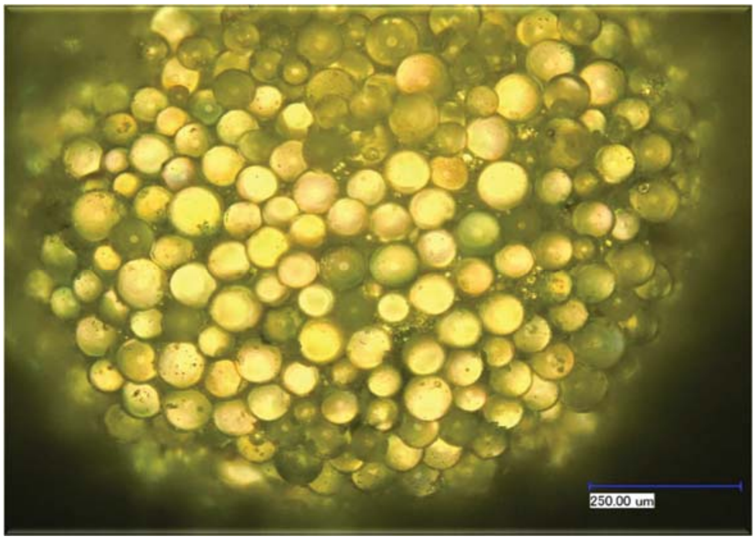
Background

MOUNTAIN-PLAINS CONSORTIUM



Microscopic View of a Single WRE

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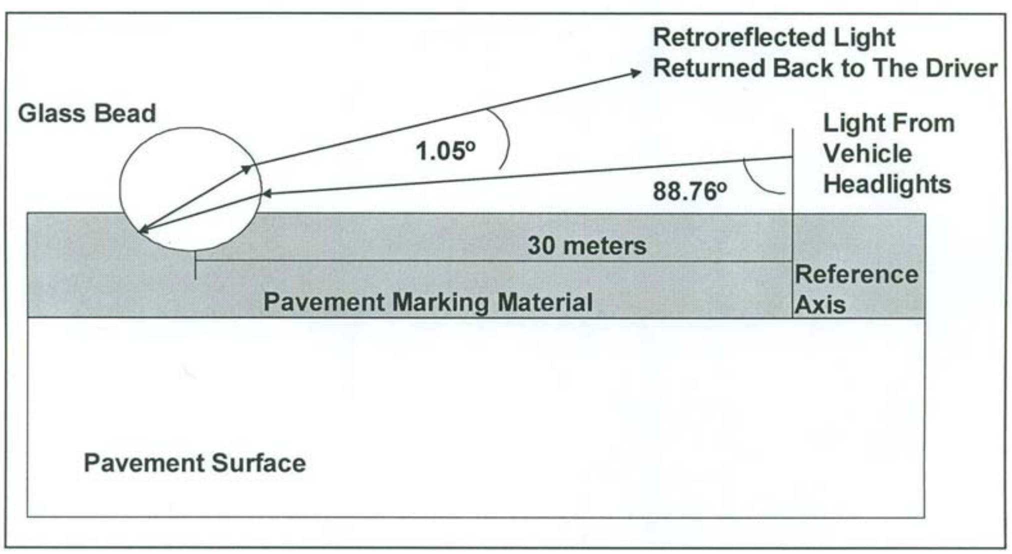
Background

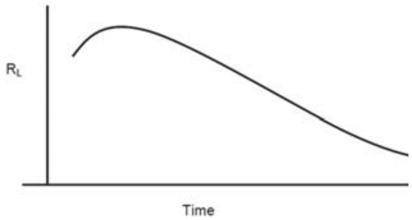
MOUNTAIN-PLAINS CONSORTIUM

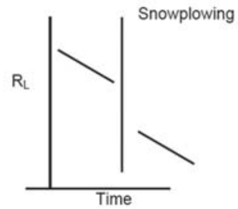


Retroreflectivity 30-meter Geometry

Background

- Retroreflectivity Degradation





- Retroreflectivity Threshold
  - ➢ FHWA
    - o White Paint: 85 to 150 mcd/m^2/lux
    - o Yellow Paint: 55 to 100 mcd/m^2/lux
  - ➢ SDDOT:
    - o White Paint: 100 mcd/m^2/lux

Depends on posted speed limits

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Background

- Initial cost and durability are functions of
  - ➢ Marking material and application rate
  - ➢ Surface preparation method
  - ➢ Winter maintenance
- Need to optimize pavement marking for cost and performance

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Objectives

1. Evaluate constructability, durability, and visibility of ***waterborne paint*** alternatives on asphalt paint surfaces
2. Compare the constructability, durability, and visibility of ***waterborne paint*** alternatives to inlayed ***epoxy paint*** applications on concrete pavements
3. Assess the cost-effectiveness of pavement marking alternatives for use on concrete and asphalt pavements

Field Data – Parameters

- Paint Type
  - Waterborne – Type II (State Specs)
  - Waterborne – Type III (High Build)
    - Type III → greater thicknesses and higher adhesion
  - Epoxy – Slow Dry (Type II)
- Paint Thickness:
  - 15 mils
  - 17 mils
  - 20 mils
  - 25 mils

Field Data – Parameters

- Paint Color:
  - White
  - Yellow
- Reflective Element (4 types + 1 WRE):
  - AASHTO M247 Type I
  - Iowa DOT Specifications (Iowa Blend)
  - SDDOT Megablend
  - P40 Gradation
  - WRE (proprietary product)

Field Data – Parameters

- Line Type:
  - Edge Line
  - Skip Line
- Pavement Type
  - Asphalt Concrete (AC)
  - Portland Cement Concrete (PCC)
- Pavement Preparation:
  - Surface Applied
  - Inlayed (recessed)

Field Data – Parameters

- Winter Maintenance Region:
  - Dry Freeze
  - Wet Freeze
- Parametric Combinations: 69 test sections

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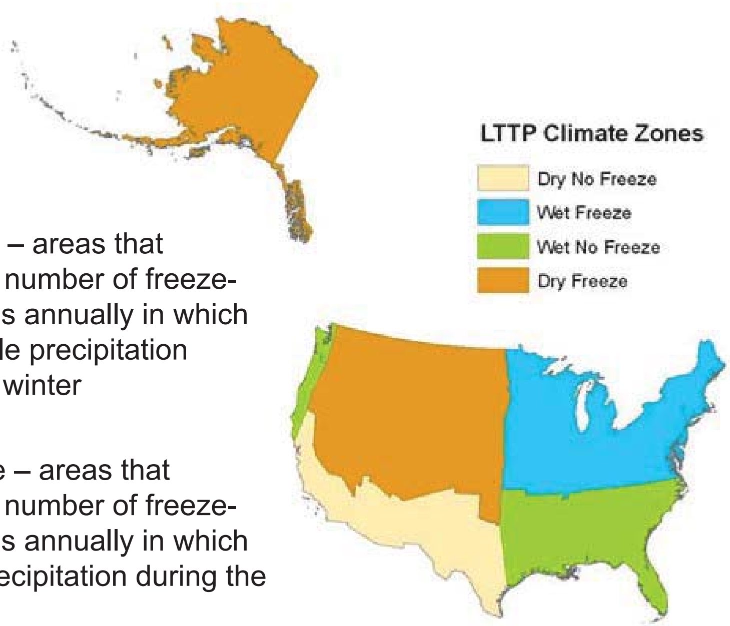
Wet Freeze / Dry Freeze



Dry freeze – areas that undergo a number of freeze-thaw cycles annually in which there is little precipitation during the winter

Wet freeze – areas that undergo a number of freeze-thaw cycles annually in which there is precipitation during the winter

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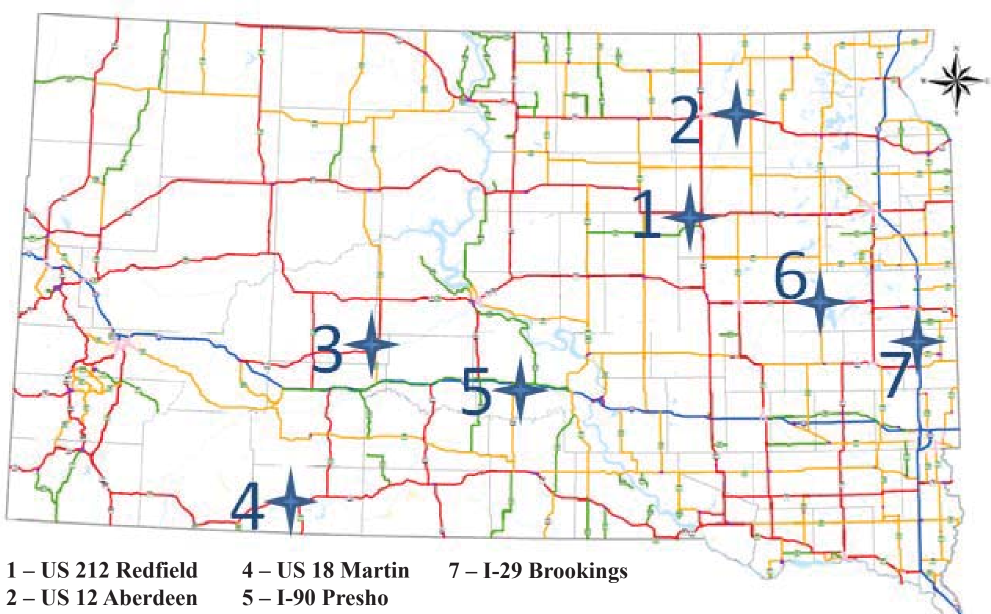
Test Deck vs. Test Section

- Test Decks
  - ➢ Extensive testing of different products / combinations
  - ➢ Better experimental control
- Test Sections (used in study)
  - ➢ Use existing projects (lower cost)
  - ➢ Good geographic representation
  - ➢ Focus on evaluating external impact factors
  - ➢ Develop state or regional calibration factors
  - ➢ Evaluate inlayed technology

Field Data – Test Sites



1 – US 212 Redfield
2 – US 12 Aberdeen
3 – US 14 Midland
4 – US 18 Martin
5 – I-90 Presho
6 – US 14 De Smet
7 – I-29 Brookings

Field Data – Test Sites

- Test Sites: 7 total
  - ➢ Waterborne Paint, Dry Freeze Regions
    - o US 212, Redfield (AC/Surface)
    - o US 212, Aberdeen (PCC/Surface)
  - ➢ Waterborne Paint, Wet Freeze Regions
    - o US 14, Midland (AC/Surface)
    - o US 18, Martin (PCC/Surface)
    - o I-90, Presho (AC/Inlay, 1 PCC/Inlay yellow)
  - ➢ Epoxy Paint, Dry Freeze
    - o US 14, DeSmet (PCC/Inlay)
    - o I-29, Brookings (PCC/Inlay and Surface)

Field Data – Measurement

- Long-term Observations
  - ➢ Measurement monthly 1st year
  - ➢ Measurement every four months 2nd Year
- Retroreflectivity
  - ➢ Portable retroreflective measurement device
  - ➢ 3 readings at 4 locations averaged
  - ➢ Wet/Dry reading on WRE
- Visual Rating
  - ➢ 1-10 Scale (Percent Marking Remaining)
  - ➢ 4 locations averaged
  - ➢ Photograph at each location

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Field Data – Measurement

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- Color
  - Chroma Meter
- Dried Paint Thickness
  - Metal Plates
- Reflective Element density
  - 1 inch Macro High-Resolution Photograph
- Other observations
  - General pavement condition
  - Temperature
  - Restriping/Chips seals

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Field Data – Measurements

MOUNTAIN-PLAINS CONSORTIUM

- Metal Plates:

  Paint Thickness

- Retroreflectivity:

  Quantitative measure of night time visibility

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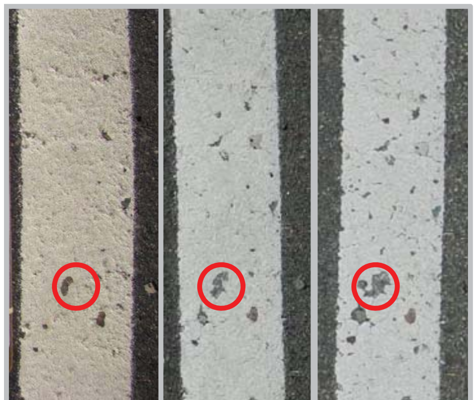
Field Data – Measurements

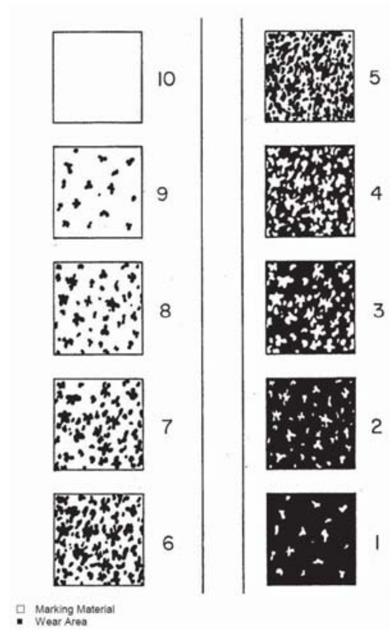
MOUNTAIN-PLAINS CONSORTIUM

- Visual Rating:

  Daytime qualitative assessment



6.1 Months	10.6 Months	20.4 Months



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Field Data – Measurements

MOUNTAIN-PLAINS CONSORTIUM

Template for Taking High Resolution Digital Photographs

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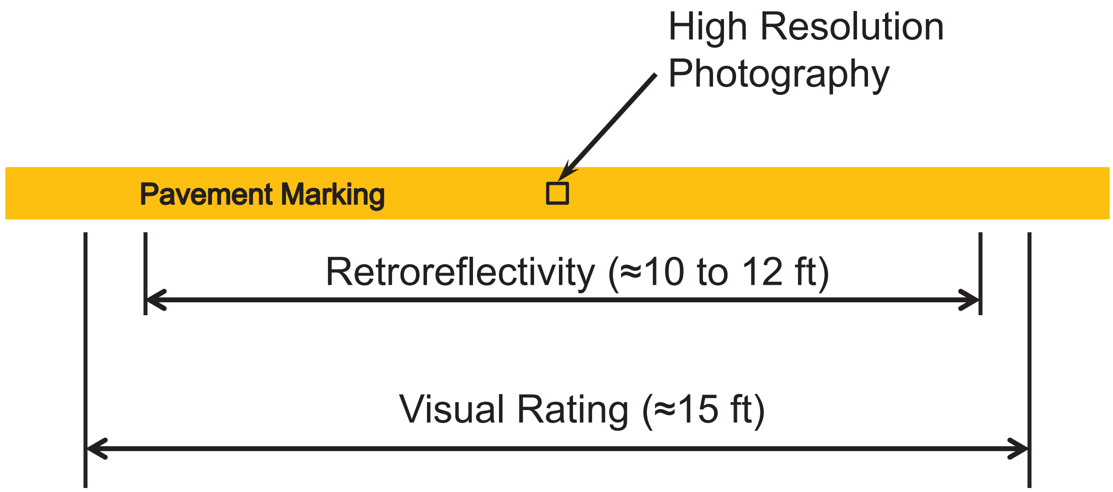
Field Data – Measurements

MOUNTAIN-PLAINS CONSORTIUM



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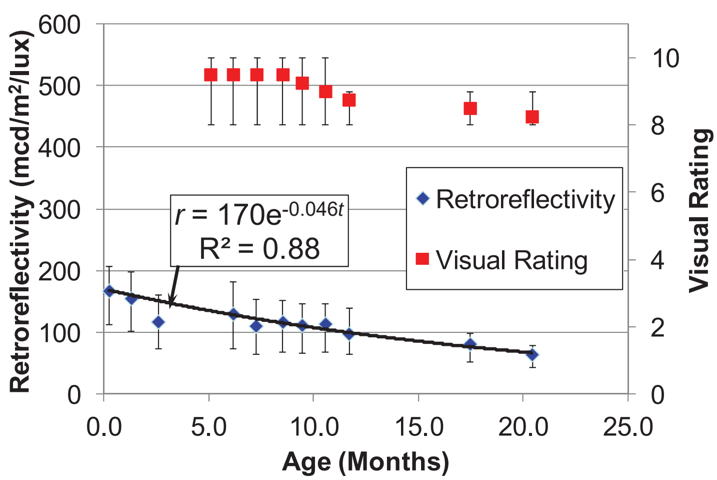
Data Analysis – Retro Decay

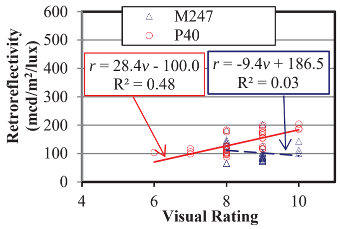
MOUNTAIN-PLAINS CONSORTIUM

- Retroreflectivity vs. Age
  - Exponential decay model: $r = A\, e^{-B \cdot t}$

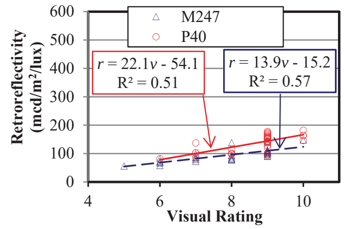


Data Analysis – Retro vs. VR

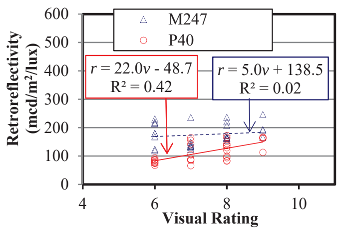
- Retroreflectivity vs. Visual Rating



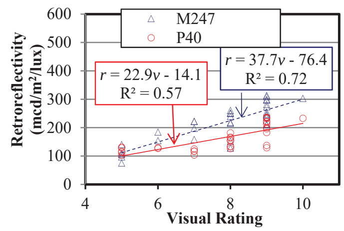
Type II, 15mils, WEL on AC



Type II, 17mils, WEL on AC



Type III, 17mils, WEL on AC



Type III, 20mils, WEL on AC

40 cases

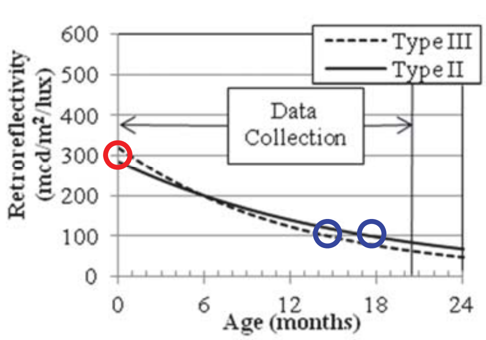
R^2 = 0.02~0.84

25 cases: $R^2 < 0.50$

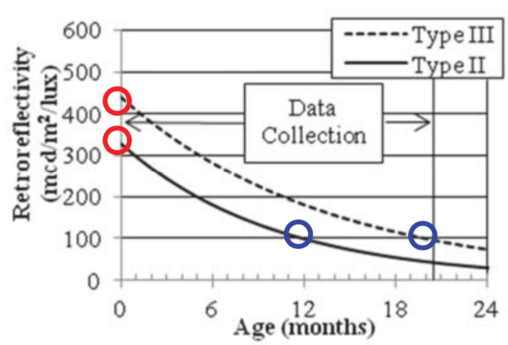
5 cases: $R^2 > 0.70$

Effect of Waterborne Paint Type (Type II vs. Type III)

- ➢ 17 mils, PCC in dry freeze region



M247, Redfield

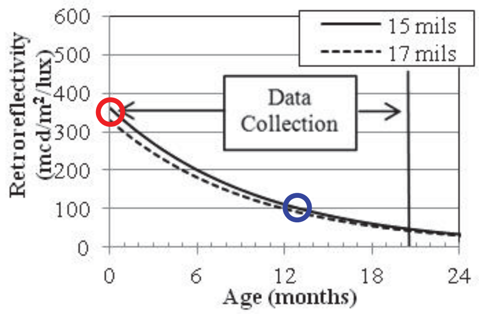


P40, Redfield

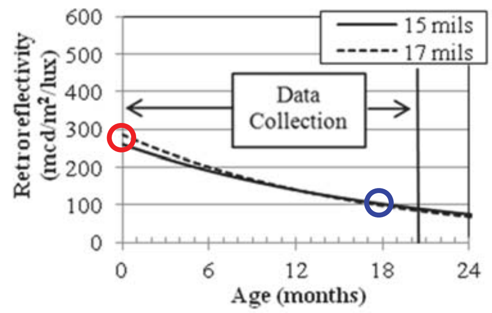
- ✓ With P40, initial retro is higher in Type III
- ✓ Decay rate is almost similar

Effect of Paint Thickness (15 mils vs. 17 mils)

- **WEL**, Type II, AC in dry freeze region



M247, Redfield



P40, Redfield

✓ Initial retro is almost similar
✓ Decay rate is almost similar

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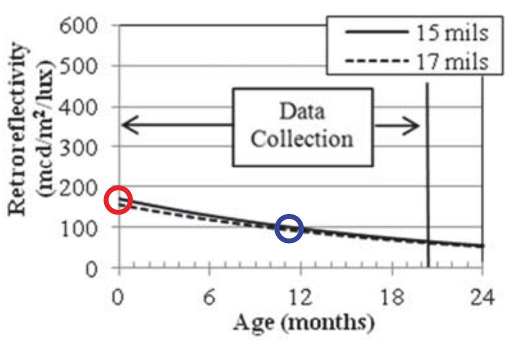
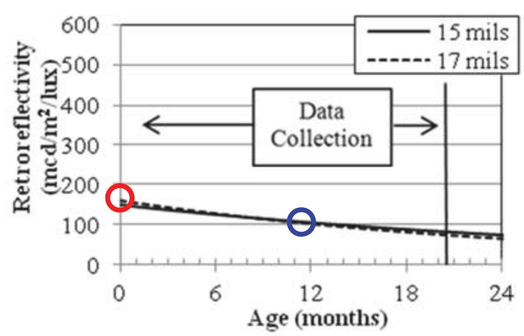
Effect of Paint Thickness (15 mils vs. 17 mils)

- **YSL**, Type II, AC in dry freeze region



M247, Redfield



P40, Redfield

✓ Low initial retroreflectivity
✓ Decay rate is almost similar

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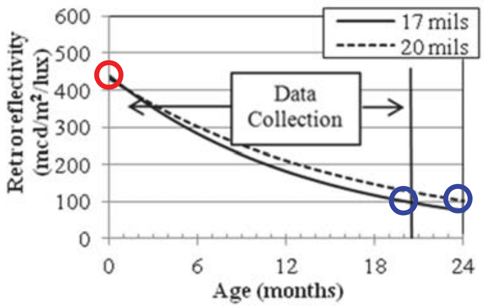
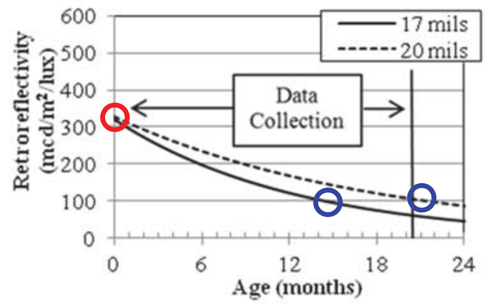
Effect of Paint Thickness (17 mils vs. 20 mils)

➢ WEL, Type III, **AC** in dry freeze region



M247, Redfield



P40, Redfield

✓ Initial retro is almost similar

✓ Decay rate in 17 mils is slightly higher

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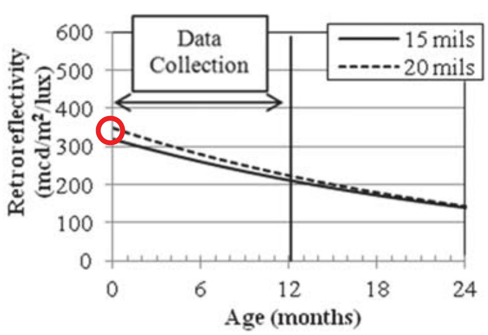
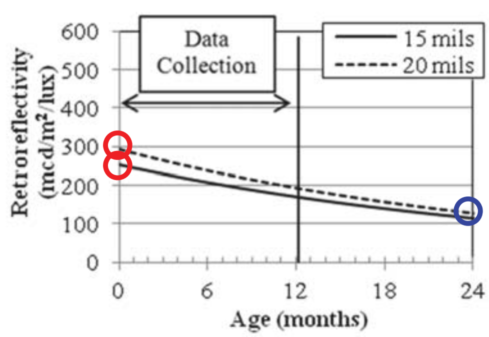
Effect of Paint Thickness (15 mils vs. 20 mils)

➢ WEL, Type III, **PCC** in dry freeze region



M247, Aberdeen



Iowa Blend, Aberdeen

✓ Initial retro of 20 mils is slightly higher

✓ Decay rate is almost similar

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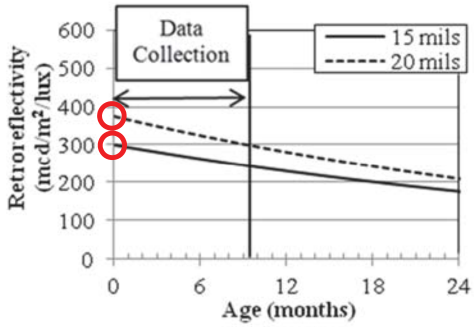
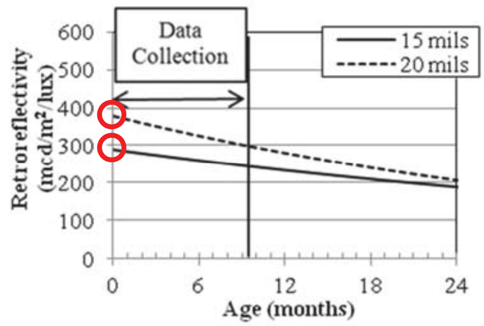
Effect of Paint Thickness (15 mils vs. 20 mils)

➢ WEL, Type III, **PCC** in **wet** freeze region



M247, Aberdeen



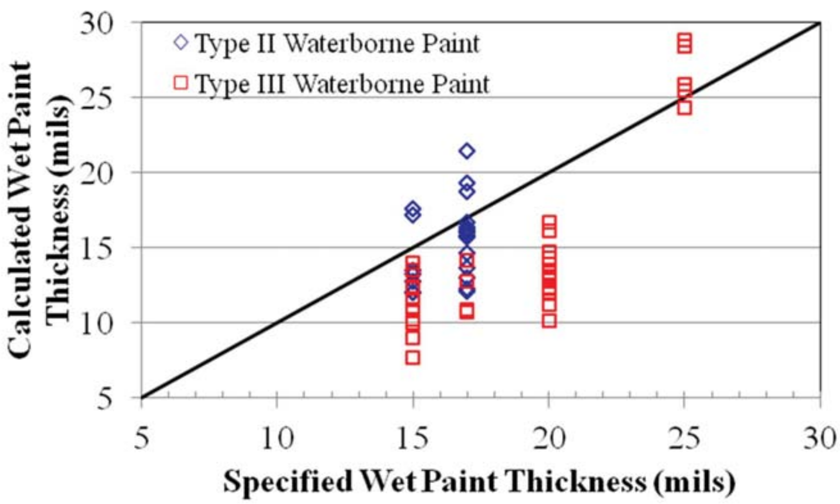
Iowa Blend, Aberdeen

✓ Initial retro of 20 mils is higher

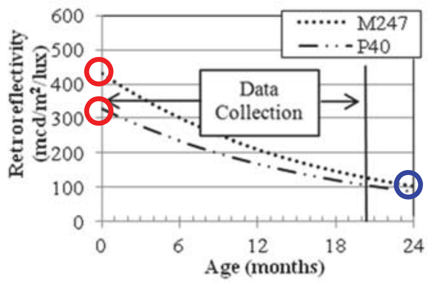
✓ Decay rate of 20 mils is slightly higher

Paint Thickness Verification

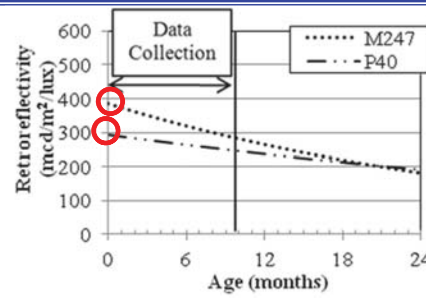
- Wet paint thickness back calculated from dry plate paint thickness



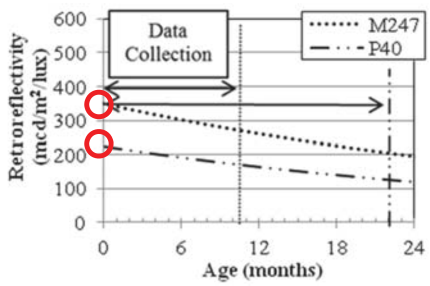
Effect of Reflective Element (M247 vs. P40 – Waterborne)



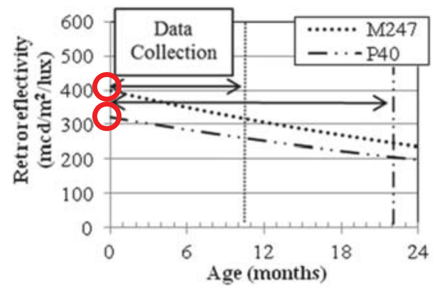
WEL, Type III, 20 mils, AC in Dry Freeze



WEL, Type III, 20 mils, AC in Wet Freeze

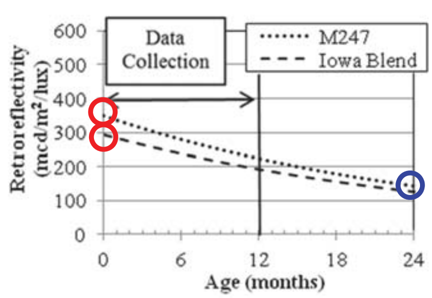


WEL, Type II, 17 mils Inlayed, AC in Dry Freeze

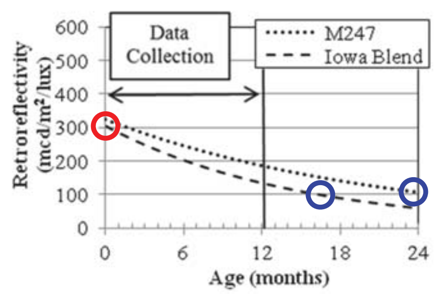


WEL, Type II, 17 mils Inlayed, AC in Wet Freeze

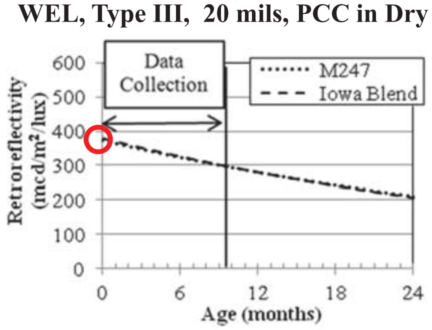
Effect of Reflective Element (M247 vs. Iowa Blend – Waterborne)



WEL, Type III, 20 mils, PCC in Dry Freeze



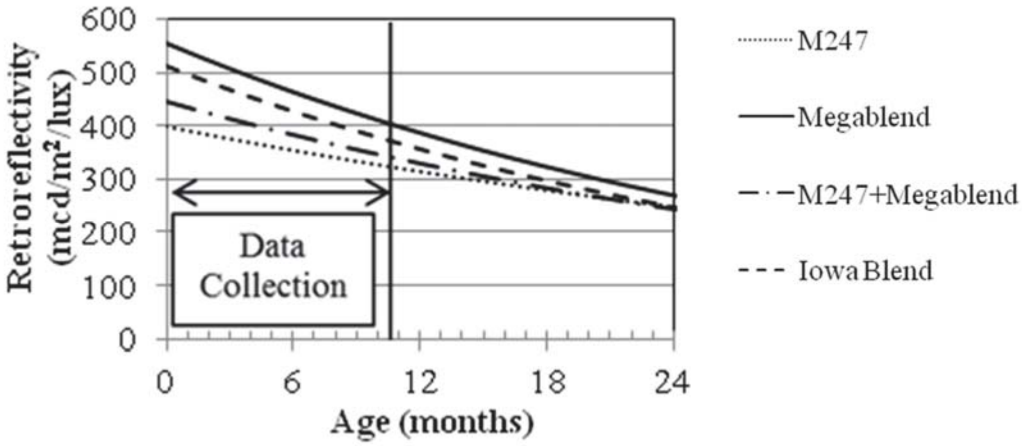
WSL, Type III, 20 mils, PCC in Dry Freeze



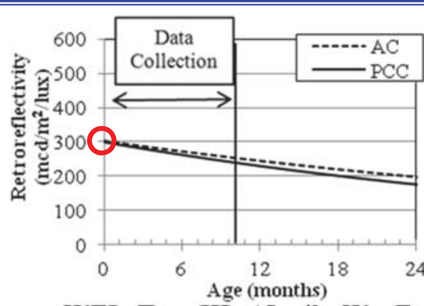
WEL, Type III, 20 mils, PCC in Wet Freeze

Effect of Reflective Element in Inlayed Epoxy

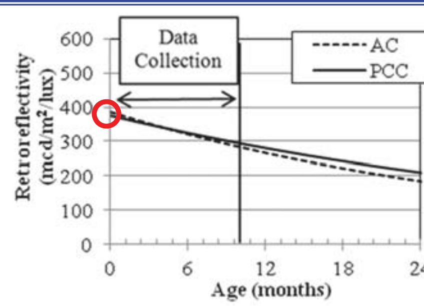
- WEL, Epoxy, **PCC** in dry freeze region



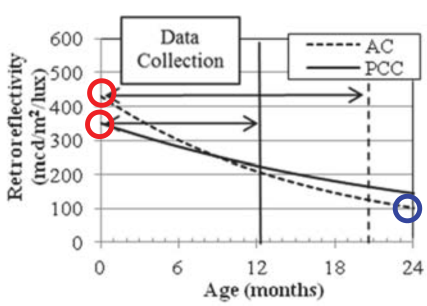
Effect of Pavement Type (AC vs. PCC – M247, Surface)



WEL, Type III, 15 mils, Wet Freeze



WEL, Type III, 20 mils, Wet Freeze



WEL, Type III, 20 mils, Dry Freeze

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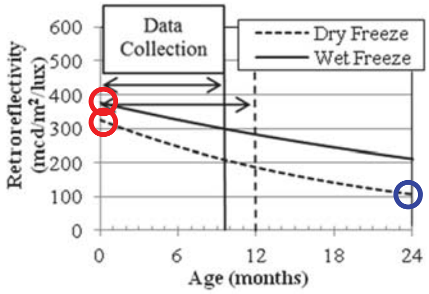
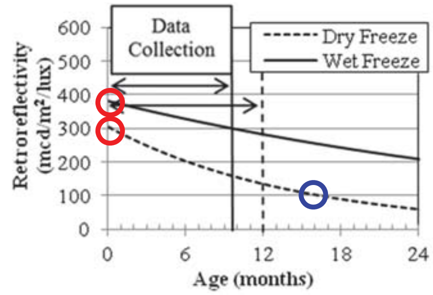
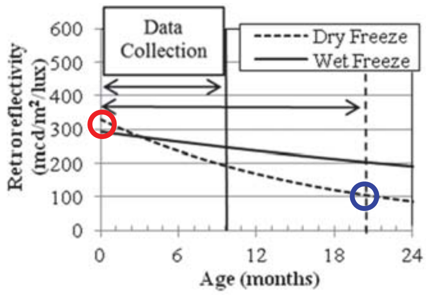
Effect of Winter Maintenance (Wet vs. Dry Freeze – Surface)



WEL, Type III, 20 mils, M247, PCC



WEL, Type III, 20 mils, Iowa Blend, PCC



WEL, Type III, 20 mils, P40, AC

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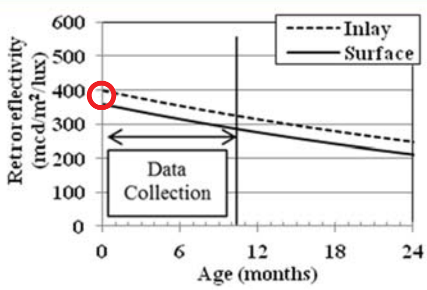
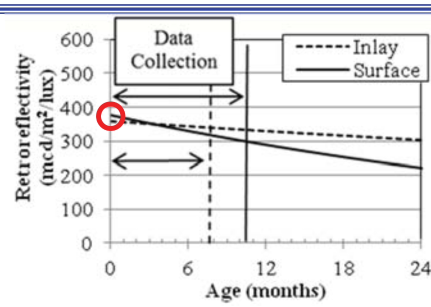
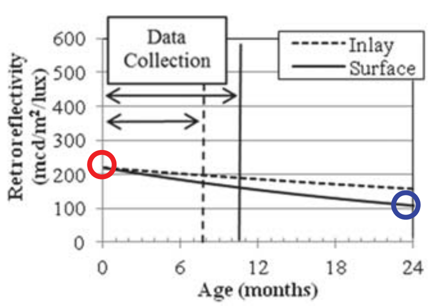
Effect of Surface Preparation (Surface vs. Inlay – Epoxy)



WEL, 20 mils, M247, PCC, Dry Freeze



WSL, 20 mils, M247, PCC, Dry Freeze



YEL, 20 mils, M247, PCC, Dry Freeze

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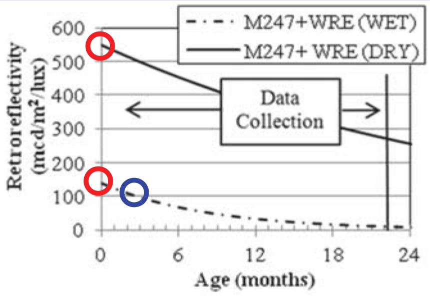
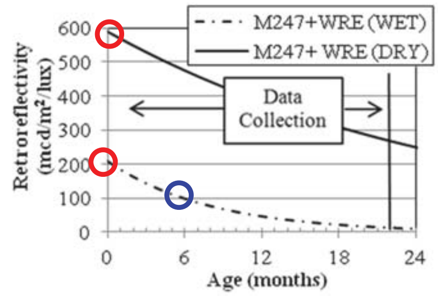
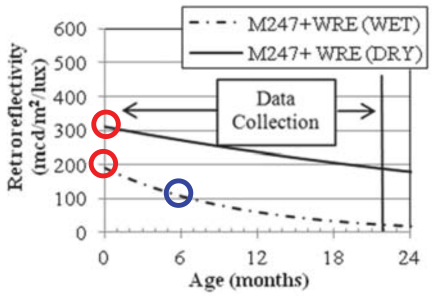
Wet Retroreflectivity
M247 + WRE – Type III Paint



WEL, 25 mils, Inlay, AC, Wet Freeze



WSL, 25 mils, Inlay, AC, Wet Freeze



YEL, 25 mils, Inlay, AC, Wet Freeze

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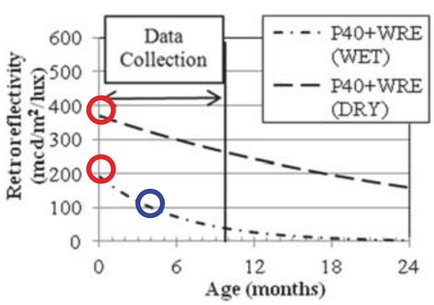
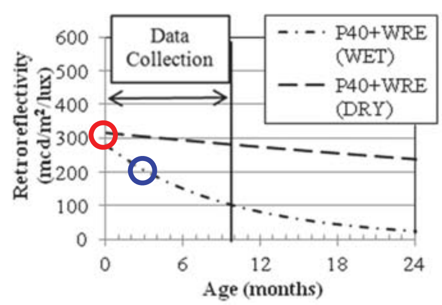
South Dakota State University

Wet Retroreflecivity
M247 + WRE – Epoxy Paint



WEL, 20 mils, Inlay, PCC, Dry Freeze



YSL, 20 mils, Inlay, PCC, Dry Freeze

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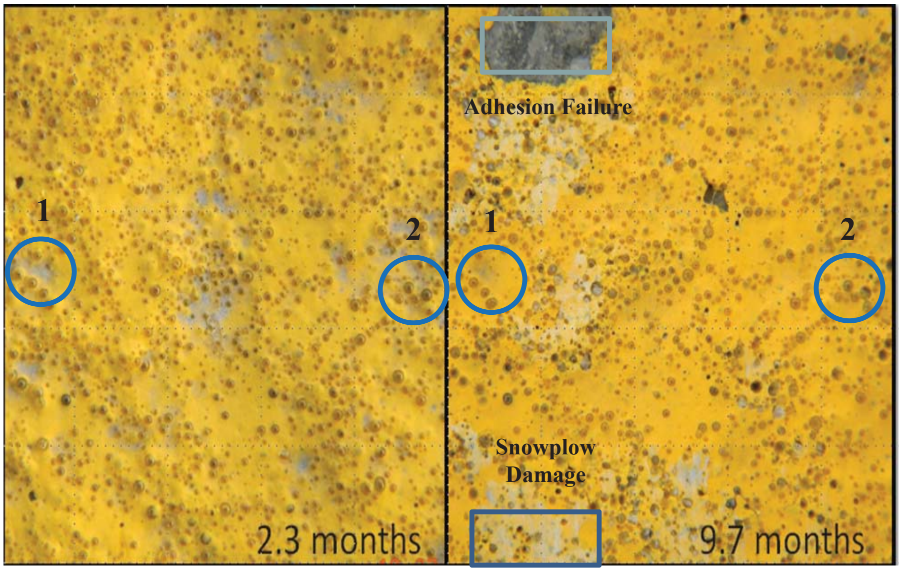
Digital Photograph Comparison



Note loss of reflective elements

Cost Analysis Spreadsheet

- Spreadsheet was developed for cost comparison of different alternatives
- Unit cost is calculated as $/mile/year
- Marking life expectancy is based on:
  - Exponential decay models
  - Minimum retroreflectivity of 100 mcd/m^2/lux

Cost Analysis Spreadsheet

- Spreadsheet returns a caution message when a model is based on limited data (short time range usually less than 12 months)
- Selecting pavement marking materials is based on making combination life expectancy (similar to life cycle cost)

Cost Analysis Spreadsheet

SOUTH DAKOTA DOT — DEPARTMENT OF TRANSPORTATION

Library:
- Dry Freeze - AC - Type II -WEL- 15 mils - Surface - w/M247
- Dry Freeze - AC - Type III -WEL- 20 mils - Surface - w/M247
- Dry Freeze - AC - Type III -WEL- 20 mils - Surface - w/P40

WEL=White Edge Line
WSL=White Skip Line
YEL=Yellow Edge Line
YSL=Yellow Skip Line

Defined Retroreflectivity (R_L) Minimum Standard: 100 (mcd/m²/lux) Minimum R^2: 0.5

Winter Maintenance Region: Dry Freeze (East River) ← Error has been fixed

Pavement Type: Asphalt

Paint Color: White

Option A	Option B	Option C
Paint Type: Waterborne Paint Type II (State Spec.)	Paint Type: Waterborne Paint Type III (High Build)	Paint Type: Waterborne Paint Type III (High Build)
Line Type: Edge	Line Type: Edge	Line Type: Edge
Wet Paint Thickness: 15 mils	Wet Paint Thickness: 20 mils	Wet Paint Thickness: 20 mils
Reflective Elements: AASHTO M 247, Type I Gradation	Reflective Elements: AASHTO M 247, Type I Gradation	Reflective Elements: P40 Gradation
Pavement Preparation: None (Typical Air)	Pavement Preparation: None (Typical Air)	Pavement Preparation: None (Typical Air)

Pavement Marking Combination A:		Pavement Marking Combination B:		Pavement Marking Combination C:	
Degradation Equation:	R=360e^(-0.098*months)	Degradation Equation:	R=430e^(-0.06*months)	Degradation Equation:	R=330e^(-0.056*months)
Equation R^2:	0.62	Equation R^2:	0.92	Equation R^2:	0.73
Equation Data Set Age (Months):	20.4	Equation Data Set Age (Months):	20.4	Equation Data Set Age (Months):	20.4
Initial R_L (mcd/m²/lux):[A]=	360	Initial R_L (mcd/m²/lux):	430	Initial R_L (mcd/m²/lux):	330
Decay Factor:[B]=	-0.098	Decay Factor:	-0.06	Decay Factor:	-0.056
Life Expectancy (Months):	13	Life Expectancy (Months):	24	Life Expectancy (Months):	21
Cost ($/Mile/Year):	298	Cost ($/Mile/Year):	214	Cost ($/Mile/year):	244

Cost Analysis Spreadsheet

		Minimum R^2	0.5								
		Retroreflectivity Standard (R_L)	100								
		Product Combinations	Cost per length per Time ($/Mi/Yr)	Equation: $R_L = A*e^{(B*months)}$	R^2	Age of Data Set (months)	Theoretical Life Expectancy	Initial R_L (A) (mcd/m²/lux)	Decay Factor (B)	Gallons of Paint per mile (gal)	Pounds of glass spheres per mile of marking (lb)
Asphalt	Waterborne Type II (State Spec.)	Surface WEL 15 mils w/M247	298	R=360e^(-0.098*months)	0.62	20.4	13	360	-0.098	16.5	132
		Surface WEL 15 mils w/P40	212	R=260e^(-0.052*months)	0.84	20.4	18	260	-0.052	16.5	132
		Surface WEL 17 mils w/M247	362	R=330e^(-0.1*months)	0.71	20.4	12	330	-0.1	18.3	147
		Surface WEL 17 mils w/P40	244	R=285e^(-0.059*months)	0.79	20.4	18	285	-0.059	18.3	147
		Surface YSL 15 mils w/M247	87	R=170e^(-0.046*months)	0.88	20.4	12	170	-0.046	4.1	33
		Surface YSL 15 mils w/P40	74	R=150e^(-0.03*months)	0.57	20.4	14	150	-0.03	4.1	33
		Surface YSL 17 mils w/M247	116	R=155e^(-0.046*months)	0.89	20.4	10	155	-0.046	4.6	37
		Surface YSL 17 mils w/P40	Error/Low R^2	R=160e^(-0.038*months)	0.36	20.4	12	160	-0.038	4.6	37
	Waterborne Type III (High Build)	Surface WEL 17 mils w/M247	216	R=440e^(-0.074*months)	0.72	20.4	20	440	-0.074	18.3	147
		Surface WEL 17 mils w/P40	298	R=320e^(-0.08*months)	0.54	20.4	15	320	-0.08	18.3	147
		Surface WEL 20 mils w/M247	214	R=430e^(-0.06*months)	0.92	20.4	24	430	-0.06	22.0	176
		Surface WEL 20 mils w/P40	244	R=330e^(-0.056*months)	0.73	20.4	21	330	-0.056	22.0	176

Wet Freeze - AC - Type II -WEL- 17 mils - Inlay - w/P40 WEL=White Edge Line
Wet Freeze - PCC - Type III -YSL- 15 mils - Surface - w/Iowa WSL=White Skip Line
Dry Freeze - PCC - Epoxy -WEL - 20 mils - Inlay - w/M247+Mega YEL=Yellow Edge Line
Defined Retroreflectivity (R_L) Minimum Standard: 100 (mcd/m²/lux) Minimum R^2: 0.5 YSL=Yellow Skip Line

Winter Maintenance Region: Wet Freeze (East River)
Pavement Type: Portland Cement
Paint Color: White

Option A		Option B		Option C	
Paint Type:		Paint Type:		Paint Type:	
Waterborne Paint Type II (State Spec.)		Waterborne Paint Type II (State Spec.)		Waterborne Paint Type II (State Spec.)	
Line Type:		Line Type:		Line Type:	
Edge		Edge		Edge	
Wet Paint Thickness:		Wet Paint Thickness:		Wet Paint Thickness:	
15 mils		17 mils		17 mils	
Reflective Elements:		Reflective Elements:		Reflective Elements:	
AASHTO M 247, Type I Gradation		P40 Gradation		AASHTO M 247, Type I Gradation	
Pavement Preparation:		Pavement Preparation:		Pavement Preparation:	
None (Typical Air)		Grooving (Inlay)		Surface Preparation	
Pavement Marking Combination A:		Pavement Marking Combination B:		Pavement Marking Combination C:	
Degradation Equation:	Check Library	Degradation Equation:	Check Library	Degradation Equation:	Check Library
Equation R^2:	Check Library	Equation R^2:	Check Library	Equation R^2:	Check Library
Equation Data Set Age (Months):	Check Library	Equation Data Set Age (Months):	Check Library	Equation Data Set Age (Months):	Check Library
Initial R_L (mcd/m²/lux):[A]=	Check Library	Initial R_L (mcd/m²/lux):	Check Library	Initial R_L (mcd/m²/lux):	Check Library
Decay Factor:[B]=	Check Library	Decay Factor:	Check Library	Decay Factor:	Check Library
Life Expectancy (Months):	Check Library	Life Expectancy (Months):	Check Library	Life Expectancy (Months):	Check Library
Cost ($/Mile/Year):	Check Library	Cost ($/Mile/Year):	Check Library	Cost ($/Mile/year):	Check Library

Conclusions

- Visual Rating may be used for casual qualitative inspection but is not adequate for assessing night time visibility.
- The back calculated paint thickness was not in agreement with the specified paint thickness.
- The decay rates of Type II and Type III paints were practically similar.
- The initial retroreflectivity of yellow paint was consistently lower than that of white paint (less than 200 mcd/m^2/lux for most cases).

Conclusions

- The retrorefectivity of yellow paint normally deteriorated in less than one year.
- Changing the ***specified*** paint thickness (15, 17, 20 mils) of waterborne paint resulted in marginal change in initial retroreflectivity and decay rate.
- The retroreflectivity of M247 in waterborne paint was consistently higher than that of P40, but did not result in practically better life expectancy.

Conclusions

- The retroreflectivity of M247 in waterborne paint was equal to or marginally higher than that of Iowa Blend, but the decay rates of the two elements were practically identical.
- Changing the reflective elements in epoxy paint resulted in noticeable change in initial retroreflectivity (Megablend > Iowa Blend > Megablend + M247 > M247). However, the life expectancies were practically identical.
- The performance of surface-applied waterborne paint with M247 on AC was almost identical to that on PCC.

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Conclusions

- The retroreflectivity deterioration rate of waterborne paint in dry freeze regions was in general higher than that in wet freeze regions.
- The retroreflectivity deterioration rate of inlayed epoxy paint was in general less than that of surface-applied epoxy paint.
- The addition of WRE in both waterborne and epoxy paints may initially result in marginal benefit to wet retroreflectivity. However, the wet retroreflectivity deteriorates at a high rate (one year or less).

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Recommendations and Implementation

- Development of a more robust quality control procedure for evaluating the actual pavement markings thickness and application rates of reflective elements.
- Maintenance regions should implement full-term evaluation studies on pavement marking degradation in their respective regions. The collected data can be used to update the decay models in the cost comparison spreadsheet.
- The cost comparison spreadsheet combined with other factors can be used to aid in selecting the optimum pavement marking.

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Cost Spreadsheet

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