



Use of Warranties and Retroreflectivity Values in Pavement Marking

Requested by
Atifa Ferouz, Division of Traffic Operations

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Executive Summary

Background

A Caltrans Nonstandard Special Provision (NSSP) identifies material warranty-based provisions for pavement marking tape, with a warranty period of five years for longitudinal markings and two years for symbols and legends. Caltrans is exploring innovative solutions in warranty-based pavement markings that will help expand on the current NSSP.

In connection with the proposed revision to the NSSP, Caltrans is interested in learning about other states' practices for establishing and monitoring warranty-based pavement marking programs, with a particular interest in initial and retained retroreflectivity values. Caltrans' interest in retroreflectivity values extends beyond warranty-based programs to include nonwarranty uses of retroreflectivity values in monitoring pavement markings.

To assist with this effort, CTC conducted a survey of state departments of transportation (DOTs) to gather information about the structure, administration, costs and other criteria associated with warranty-based pavement marking programs, and the warranty and nonwarranty applications of minimum retroreflectivity values to assess pavement marking performance. The survey findings are supplemented by specifications and other documents related to the application of warranties and minimum retroreflectivity values, and the results of a limited review of relevant published and in-process research.

Summary of Findings

Survey of State Practice

Two online surveys were distributed to members of the AASHTO Subcommittee on Traffic Engineering:

- The first survey sought information about the use of warranties for pavement markings, and also included questions about the use of minimum retroreflectivity values for those agencies applying them.
- The second survey addressed the use of minimum retroreflectivity values to evaluate pavement marking performance outside of a warranty.

Respondents were asked to complete the survey that best matched their agency's experience.

The two surveys are examined separately in this Preliminary Investigation, with the exception of survey questions related to the warranty and nonwarranty applications of retroreflectivity values. Responses to these questions are summarized together and appear in the presentation of results for the survey on retroreflectivity values.

Survey on Warranties

The survey on warranties received a very limited response, with only four state DOTs—Alabama, Kansas, Oregon and Virginia—responding. (Oregon DOT provided two responses.) Incomplete survey responses further limited survey findings.

Warranty Program Description

Respondents were asked to describe the type of warranty associated with their pavement marking programs from among four categories—workmanship, materials, materials and workmanship, and performance. Alabama and Oregon DOTs apply a materials warranty; Kansas and Virginia DOTs reported a materials and workmanship warranty.

Alabama and Kansas DOTs maintain statewide warranty programs; the Oregon and Virginia DOT respondents reported a more limited approach and apply warranties based on the type of marking material. Warranty periods often vary based on material type. The time periods ranged from Oregon DOT's one-year warranty for modified urethane, polyurea and high-build paint pavement marking applications to the six-year warranty applied by Alabama and Virginia DOTs. The material-specific warranties applied by Kansas DOT range from three to seven years.

Performance Monitoring

Respondents provided few details about practices for tracking the pavement segments covered under a warranty. Oregon DOT is the only agency to report the use of a designated staff person to oversee the warranty program. The agency's statewide coordinator for warranties serves as the point of contact for manufacturers and the local striping maintenance managers who are considered the holder of a warranty after project acceptance. Oregon DOT's coordinator maintains a spreadsheet to track pavement marking installations, including project location, quantities, unit prices, material used and warranty duration.

None of the respondents reported a formal schedule of performance inspections. Inspections are made on a random basis or upon request, and all four agencies conduct inspections using agency staff. When a marking fails to comply with the warranty, both Oregon and Virginia DOTs require correction or repair. Kansas DOT takes a different approach, basing replacement of the marking on the amount of pavement marking failure and also considering a pay reduction based on the total amount of the failure.

Financial Practices

Respondents again offered little detail on the financial practices associated with their warranty programs. None of the respondents apply a payment schedule to projects under warranty, and none maintain a separate budget to monitor warranties. All but one of the respondents requires project bonding, but respondents provided no details about determining bond values.

Oregon DOT's statewide coordinator for warranties is the only indication of a significant additional resource used to administer a warranty program. When asked how costs differ between warranty-related pavement markings and nonwarranty markings, one of the Oregon DOT respondents noted that the agency "ha[s] not formally studied the cost impacts of our warranty program, but we suspect costs are increased to the agency so the manufacturer can manage risk."

Program Administration

For three states, project acceptance involves an evaluation of retroreflectivity values. Only one respondent, from Oregon DOT, provided some level of detail about a dispute resolution process. The agency's process allows the manufacturer six months to repair the product failure. If the repair is made in accordance with specifications, the warranty clock resumes. If the

manufacturer does not resolve the issue, the failed product is removed from the agency's qualified product list.

Regarding warranty program features that might help improve vendor and product performance, only one feature is part of all four respondents' pavement marking warranty programs—the use of a qualified product list.

Successes and Challenges

Kansas DOT has identified an increase in the quality of markings as a result of holding both the contractor and manufacturer accountable for pavement markings under the warranty. Oregon DOT noted that its warranty program has been effective overall—less than 5 percent of the agency's construction projects have had a warranty issue.

When asked what has proved to be particularly challenging in managing their warranty programs, two respondents highlighted challenges associated with contractors.

Survey on Retroreflectivity Values

The survey on retroreflectivity values received a greater response than the warranty survey, with 12 state DOTs responding. One of the respondents indicated that his agency “does not officially require any minimum retroreflectivity values,” and few respondents elected to respond to all questions in the survey. As a result, findings are limited in some areas.

Retroreflectivity Program Description

All responding states except South Dakota apply minimum retroreflectivity values at the statewide level, and most respondents subject all pavement marking projects to monitoring. Among the methods used to identify and track the pavement segments being monitored for retroreflectivity values are the use of sample sizes as part of the agency's maintenance rating program (Kentucky) and contractor audit (North Carolina).

Minimum and Retained Retroreflectivity Values

Most respondents offered minimum retroreflectivity values for a range of pavement marking materials; see the table on page 17 of this Preliminary Investigation for detailed information.

The most common time frame for measuring the initial retroreflectivity values of a new pavement marking installation is within 30 days. Other time spans range from the immediate testing conducted by Alabama DOT to the 45 days reported by Minnesota and Missouri DOTs as the last day for a measurement.

Only three respondents reported practices that apply a minimum retained retroreflectivity value for a specified time period. Two states—Georgia and Nebraska—have a 180-day observation period for final project acceptance. Pennsylvania DOT has set minimum retroreflectivity values for its test deck that must be met for up to three years depending on the type of marking. Pennsylvania is the only state to report lowering its requirement for retained retroreflectivity as time passes.

Most respondents measure the retained retroreflectivity of pavement markings using a 30-meter retroreflectometer. Some respondents provided specifications or additional detail on their

measurement practices; for example, Minnesota districts can submit requests for staff to measure segments of markings that appear to be nearing the threshold for replacement.

Performance Inspections

Respondents offered little consensus on the conduct of performance inspections. While inspections are not conducted in Iowa and New Hampshire, annual inspections are conducted in Missouri and Nebraska. In Pennsylvania, performance inspections are conducted on the agency's test deck before a product is approved for use. Other agencies conduct random inspections or inspections upon request.

More than half of respondents conduct performance inspections with agency staff. Missouri DOT retains a third-party contractor to conduct mobile retroreflectivity readings for contractor-installed pavement markings. The contractor also takes random quality assurance readings to assist the agency in evaluating its overall pavement marking program.

Inspection results are most commonly tracked with a spreadsheet. Pennsylvania DOT goes beyond maintaining its own spreadsheet, entering inspection data into the National Transportation Product Evaluation Program database.

Failure to Meet Retroreflectivity Requirements

When a pavement marking fails to meet the agency's minimum retroreflectivity requirements, most respondents require the contractor to remove and replace the marking. Some states also consider a pay reduction associated with acceptance of a marking installation that fails to meet minimum retroreflectivity requirements. The Minnesota DOT respondent described an ongoing examination of marking performance that schedules failing markings for "refreshing."

Successes and Challenges

When asked about program successes, half of respondents noted that the application of minimum retroreflectivity values has improved vendor performance or the quality of the markings.

Respondents reported a range of challenges associated with marking installation and performance monitoring, such as the large volume of markings to track, and difficulties in getting contractors to meet minimum retroreflectivity requirements in real-world applications or to accept failing results.

Specifications, Special Provisions and Related Documents

Specifications, special provisions and other documents related to the warranty and retroreflectivity monitoring programs of 16 states are highlighted in this Preliminary Investigation. These documents include those provided by survey respondents and other publications identified through a literature search.

Related Resources

Pavement Marking Warranties

A 2010 NCHRP synthesis report that examined pavement marking warranty specifications is the most significant source of findings to supplement the surveys conducted for this Preliminary

Investigation. Among the topics addressed in a survey that netted responses from 23 transportation agencies in North America are the perceived benefits of warranties and reasons for not using them.

The most extensive examination of state practices associated with pavement marking warranties appears in a 2013 Utah DOT report that describes the agency's first experience with a six-year performance-based warranty on a portion of an Interstate 15 pavement marking project. Other state practices are considered in a 2013 FHWA report of demonstration projects in Alaska and Tennessee that addressed the application of performance-based pavement marking specifications, and in a 2010 examination of the costs and benefits of Colorado DOT's warranty specifications for epoxy pavement marking materials. A 2009 report describing Missouri DOT's evaluation of two types of marking products under warranty includes a discussion of payment schedules.

Measuring Retroreflectivity: General Guidance

Guidance provided by an in-progress Federal Aviation Administration project, an NCHRP report, conference papers and a journal article addresses the development of mobile tools to measure retroreflectivity; laboratory test methods to predict initial retroreflectivity in the field; development of a pavement marking condition index; and an evaluation of retroreflectivity measurement techniques for profiled and rumble strip markings.

Measuring Retroreflectivity: State Practices

An examination of state practices to measure retroreflectivity identified an Arkansas DOT report that describes the equipment and data collection efforts associated with establishing a pavement marking measurement system. A series of Florida DOT publications and an Iowa DOT report address the use of measurement tools, while a 2010 journal article considers a more subjective approach to assessment with its evaluation of Texas DOT's visual assessments of pavement markings. A 2011 report prepared for Kentucky Transportation Cabinet recommends new retroreflectivity levels for the agency.

Test Decks

The efficacy of test decks in evaluating the retroreflective performance of pavement markings is addressed in a recent journal article. State DOT test deck applications are considered in a Texas DOT technical report and an Oregon DOT report that describes that agency's testing and evaluation procedures.

Gaps in Findings

An examination of survey findings identified relatively little consensus among respondents with regard to the structure and administration of their pavement marking warranty programs, or the application of retroreflectivity values as they relate to pavement marking programs. Respondents appear to be charting their own courses in establishing and maintaining these programs.

Drawing conclusions from survey responses was further challenged by the extremely low response to the survey on warranties, which presented the most significant gap in findings. While more respondents completed the survey on the application of retroreflectivity values, the

survey response rate to that survey was also relatively low, and gaps in responses further limited the survey findings.

Next Steps

Moving forward, Caltrans could consider:

- Consulting with the states that responded to the warranty survey to learn more about their programs, including:
 - The role played by Oregon DOT's statewide coordinator for warranties, and the agency's dispute resolution process.
 - Kansas and Virginia DOTs' application of a materials and workmanship warranty.
 - Kansas DOT's statewide application of warranties.
- Examining the 2010 NCHRP synthesis report on pavement marking warranty specifications to learn more about the practices of the agencies responding to the survey conducted for that project.
- Identifying and contacting other states known or expected to have experience with warranties to gather more information about the application of warranties to pavement marking programs.
- Contacting agencies that apply a wide range of material-specific retroreflectivity values (Iowa, Minnesota and Pennsylvania DOTs) to learn more about how those minimum values were established.
- Consulting with Georgia, Oregon and Pennsylvania DOTs to learn more about those agencies' use of a test deck to evaluate the retroreflectivity of pavement markings.
- Examining in detail the specifications, special provisions and other documents related to pavement marking warranties and the application of minimum retroreflectivity values to identify areas of interest to Caltrans in considering modifications to its own guidance.

Detailed Findings

Survey of State Practice

We distributed two online surveys to members of the AASHTO Subcommittee on Traffic Engineering to gather information about state practices for establishing and monitoring warranty-based pavement marking programs, and the warranty and nonwarranty uses of retroreflectivity values. Respondents were asked to select and respond to the survey that best reflected their agency's practices:

- **Survey on Warranties:** A survey for state DOTs that use warranties for pavement markings. This survey included questions about the use of minimum retroreflectivity values.
- **Survey on Retroreflectivity Values:** A survey for state DOTs that do not use warranties for pavement marking but do consider minimum retroreflectivity values in evaluating pavement marking performance.

Responses to the two surveys are examined separately in this Preliminary Investigation, with two exceptions:

- Warranty and nonwarranty applications of retroreflectivity values are presented together within the survey on retroreflectivity values; see page 15 of this Preliminary Investigation.
- Specifications, special provisions and other documents supplied by all respondents are presented together in a separate section of this report; see page 25 of this Preliminary Investigation.

Presentation of survey results begins with an examination of respondents' use of warranties.

Survey on Warranties

The survey addressing warranties consisted of these questions:

1. What type of warranty do you use for pavement markings? Select all that apply.
 - *Workmanship.* Contractor controls workmanship in accordance with agency specifications; covers defects in workmanship, but contractor is not responsible for design-related failures.
 - *Materials.* Contractor warrants the performance of the material over a certain period of time in accordance with agency specifications; covers defects in the warranted materials.
 - *Materials and workmanship.* Contractor controls material and workmanship in accordance with agency specifications; covers defects in the materials and/or workmanship of the warranted items.
 - *Performance.* Warranty specifies only the required performance. Contractor selects materials and determines installation practices; contractor is responsible for any defects identified.
2. What is the extent of your warranty program for pavement markings?

- 2A. What criteria are used to determine when a project qualifies for warranty-based pavement markings?
- 2B. How do you identify and track which pavement segments have markings that are covered under a warranty?
3. What type of performance criteria apply to the warranty? Select all that apply.
 - Initial installation requirements (including initial minimum retroreflectivity)
 - Minimum retained retroreflectivity
 - Durability
 - Color retention
 - Other (please specify)
4. What is the length of the warranty period?
5. Do you have a copy of your pavement marking warranty specifications that you can share? Please provide a link below or send any file not available online to Chris Kline at chris.kline@ctcandassociates.com.
6. Please describe the certification or other process used to determine your agency's acceptance of a completed pavement marking project.
7. What is the payment schedule during the warranty period?
8. Is project bonding required?
- 8A. When is the bond required to be issued?
- 8B. How is the value of the bond determined?
9. Have you formalized a dispute resolution process to settle disputes during installation or the warranty period?
10. Which of the following practices apply to your pavement marking warranty program? Select all that apply.
 - Contractor-provided test sections
 - Materials manufacturer's training or other technical assistance
 - Prequalification of contractors
 - Qualified products lists
 - Required meetings during the warranty period that include all parties
 - Work plans or other documents required for submission by the contractor during the warranty period
 - Other (please specify)
11. How does the cost of pavement marking differ for warranty-based markings versus nonwarranty-based markings?
12. What is your budget allocation for monitoring warranty-based pavement markings?
13. What additional resources (personnel, equipment or other resources) did you require when implementing a warranty program? Consider in your response the resources

needed for program development and performance monitoring for pavement segments installed under the warranty.

14. How often are performance inspections conducted?
15. Who conducts warranty-related inspections?
16. How do you track the results of performance inspections under the warranty?
17. What types of corrective action are provided for in the warranty when a contractor or manufacturer fails to meet warranty requirements?
18. Does your agency include provisions in your warranty for minimum retroreflectivity values for pavement markings?
19. What is the warranty's required initial retroreflectivity value for pavement markings?
20. When is the initial retroreflectivity value taken?
21. What is the retained retroreflectivity value required under the warranty?
22. Does the required retained retroreflectivity value vary over the length of the warranty?
23. How is the retained retroreflectivity of a pavement marking measured?
24. What process is used to address a contractor's failure to meet required retroreflectivity values under the warranty?
25. Please provide a link to your standard specification or special provision that identifies initial and retained retroreflectivity values for pavement markings. Send any file not available online to Chris Kline at chris.kline@ctcandassociates.com.
26. What successes have you experienced in managing your warranty-based pavement marking program?
27. What challenges have you experienced in managing your warranty-based pavement marking program?
28. Please use this space to provide any comments or additional information about your answers above.

The survey received a very limited response, with only four state DOTs—Alabama, Kansas, Oregon and Virginia—responding to the survey. (Oregon DOT provided two responses.) See [Appendix A](#) to this Preliminary Investigation for the full text of these survey responses.

The survey gathered information in six topic areas related to the use of warranties for pavement markings:

- Warranty program description.
- Performance monitoring.
- Financial practices.
- Program administration.
- Successes.
- Challenges.

Along with the limited number of responses to this survey, gaps in responses to survey questions further limited the survey findings in some areas. Key findings from the survey follow.

Warranty Program Description

Type of Warranty

Respondents were asked to identify the type of warranty associated with their pavement marking programs from among four categories: workmanship, materials, materials and workmanship, and performance. The table below summarizes survey responses.

Respondents' Warranty Types	
Warranty Type	State
Materials. Contractor warrants the performance of the material over a certain period of time in accordance with agency specifications; covers defects in the warranted materials.	Alabama, Oregon
Materials and workmanship. Contractor controls material and workmanship in accordance with agency specifications; covers defects in the materials and/or workmanship of the warranted items.	Kansas, Virginia

Performance Criteria

While none of the respondents reported a performance-based warranty, respondents did describe the performance criteria that are addressed in their pavement marking specifications. The table below summarizes survey responses.

Respondents' Performance Criteria	
Criteria	State
Initial installation requirements (including initial minimum retroreflectivity)	Kansas, Oregon
Minimum retained retroreflectivity	Alabama, Oregon
Durability	Kansas, Oregon
Color retention	Alabama, Kansas, Oregon

Extent of Warranty Program

Alabama and Kansas DOTs maintain statewide warranty programs. The Oregon and Virginia DOT respondents reported a more limited approach to warranties:

- All new construction projects in Oregon not using waterborne paint have pavement marking warranty requirements. More durable materials (thermoplastics and methyl methacrylate) are warranted longer than less durable materials such as high-build paint and epoxies.
- Virginia DOT's warranties are limited to projects that specify B-VI reflective tape. This type of marking material is specified for interstate and other limited-access facilities where the pavement life is expected to be six years or more.

Length of the Warranty Period

Respondents were evenly split with regard to the length of the warranty period. Two states apply a fixed period, while the other two apply warranty periods based on material type.

Alabama and Virginia DOT respondents reported six-year warranty periods. The Alabama DOT respondent noted that the six-year warranty period applies to the longitudinal marking; a two-year warranty applies to legends and symbols.

In Kansas and Oregon, the warranty period varies by type of marking material. In Kansas, the workmanship warranty is 180 days. After that time, the manufacturer's warranty takes over, and that warranty ranges from three to seven years based on the marking material. Oregon DOT also applies different warranty periods to different materials:

- Longitudinal thermoplastic (surface-applied)—three years.
- Longitudinal thermoplastic (groove-applied)—four years.
- Longitudinal methyl methacrylate (surface- and groove-applied)—four years.
- Longitudinal tape—four years.
- Modified urethanes (surface- and groove-applied)—one year.
- High-build paint (surface- and groove-applied)—one year.
- Polyurea (surface- and groove-applied)—one year.
- All transverse bars and legends—1.5 years.

Performance Monitoring

Tracking Pavement Segments Covered by Warranty

Only the Oregon and Virginia DOT respondents shared their practices for tracking the pavement segments covered under a warranty. In Virginia, regional maintenance staff work with the districts to maintain project records. In Oregon, after a warranty project is closed, the local striping maintenance manager is the holder of the warranty. Oregon DOT's statewide coordinator for warranties acts as the point of contact for manufacturers and the agency's local maintenance managers.

The Oregon DOT statewide coordinator for warranties, one of the respondents to the survey, maintains a spreadsheet to track the installation of pavement markings. The spreadsheet includes highway and milepoint range for each project, quantities, unit prices for the markings, and the completion date. Some of this information is provided by the manufacturer through the use of a standard form that includes project location (milepoint to milepoint), date installed, material and duration of warranty.

Performance Inspections

None of the respondents reported a formal schedule of performance inspections. In Kansas and Virginia, inspections may be conducted when a route is driven by agency staff. In Oregon, inspections are conducted if the performance of a specific marking is questioned. All respondents reported completing inspections with agency staff.

In Oregon, the statewide coordinator maintains a list of projects subject to warranty, which permits tracking of the timelines of acceptance, notification and repair. Information on projects tested but not requiring warranty repair is also maintained.

Failure to Comply With Warranty

When a marking fails to comply with the warranty, both Oregon and Virginia DOTs require correction or repair. In Oregon, the warranty “time clock” stops until the repairs are accepted. The respondent also noted that if the repair is not completed, the manufacturer’s material is removed from the agency’s qualified product list.

In Kansas, replacement of a marking is required based on the amount of the pavement marking failure, and a pay reduction may be imposed based on the total amount of failure.

Financial Practices

Respondents provided relatively little detail on the financial practices associated with their warranty programs. None of the respondents reported the use of a payment schedule over the life of the warranty, and none maintain a separate budget to monitor the pavement marking warranty.

Regarding additional resources required to implement a warranty program, the Virginia DOT respondent reported that none were required. In Oregon, a statewide coordinator position was developed, and the agency purchased a handheld retroreflectometer for each pavement marking crew and the statewide coordinator’s office to inspect materials that are under warranty.

Only one respondent, from Oregon DOT, addressed a survey question about differing costs for warranty-based markings versus nonwarranty-based markings, noting this:

We have not formally studied the cost impacts of our warranty program, but we suspect costs are increased to the agency so the manufacturer can manage risk.

All but one of the four states—Kansas—require project bonding, but the respondents provided little detail about bonding practices. In Alabama and Oregon, the bond is required at the beginning of the project. The Virginia DOT respondent noted that the entire project has a bond, and the bonding is not specific to the pavement marking portion of the project. None of the respondents provided significant detail about how the value of the bond is determined, with the Oregon DOT respondent noting that the “size or value of the project determines the level of bonding required.”

Program Administration

Project Acceptance

All three respondents who described their agency’s process for project acceptance addressed the application of retroreflectivity values. In Kansas, retroreflectivity readings are taken 12 hours to 14 days after a project is complete. Once the readings have been accepted, the 180-day workmanship warranty starts.

One of the Oregon DOT respondents focused on contractor and agency activities during installation, saying:

The contractor must be certified by the material manufacturer and a manufacturer’s representative must be on-site during installation to ensure conditions are right for their material (that they’re warranting) to go down. An agency inspector ensures markings are placed in the proper location within tolerances. The contractor also must measure retroreflectivity every 300 feet to determine if the new line meets minimum standards.

The other Oregon respondent noted that the agency uses a particular test method to guide its evaluation of the retroreflectivity of pavement markings in connection with project acceptance.

According to specifications, in Virginia a visual evaluation is conducted to “assess the condition, retroreflectivity and color of the marking tape. If problem areas are found, an inspection will be made by the Department, the Contractor, and tape manufacturer’s representative to identify specific areas of concern. If needed, the suspect areas shall be tested by the Contractor and/or VDOT representative in accordance with VTM-125 to define the evaluation sections and the number of measurements needed.”

Dispute Resolution

Only one respondent, from Oregon DOT, provided detail about a dispute resolution process. The agency’s process is:

- The agency notifies the manufacturer of the product failure; the warranty period time clock stops. The manufacturer has six months to repair the product failure.
- The manufacturer contacts a contractor to make the repair.
- If the repair is made in accordance with specifications, the warranty clock resumes.
- If the repair is not made, the agency submits a letter to the manufacturer requiring a detailed plan to resolve the issue within a certain time frame. If the manufacturer does not resolve the issue, the failed product is removed from the agency’s qualified product list.

The second Oregon DOT respondent noted that in some cases, the agency has removed a company’s full product line from its qualified product list as a result of multiple failures with delinquent repairs.

Warranty Program Features

The survey asked respondents to consider a list of warranty program features that might contribute to improved vendor and product performance, and indicate those that relate to their warranty programs. The most common warranty program feature reported by respondents is the qualified product list. The table below summarizes survey responses.

Warranty Program Features Reported by Respondents	
Criteria	State
Contractor-provided test sections	Kansas, Oregon
Materials manufacturer’s training or other technical assistance	Kansas, Oregon
Prequalification of contractors	Kansas, Oregon

Warranty Program Features Reported by Respondents	
Criteria	State
Qualified product lists	Alabama, Kansas, Oregon, Virginia
Required meetings during the warranty period that include all parties	Kansas
Work plans or other documents required for submission by the contractor during the warranty period	Oregon

Successes

Two respondents listed successes associated with managing their warranty programs:

- Kansas DOT has identified an increase in the quality of markings as a result of holding both the contractor and manufacturer accountable for pavement markings under the warranty.
- One of the Oregon DOT respondents noted that less than 5 percent of the agency's construction projects have had a warranty issue. The agency has activated 110 warranties (across all types of construction projects) and only five have not been resolved.

Challenges

Regarding challenges in managing warranty programs, one of the Oregon DOT respondents noted that since the warranty is with the material manufacturer, the agency has no leverage to require the contractor to repair markings.

Survey on Retroreflectivity Values

The survey addressing the application of minimum retroreflectivity values outside of warranties consisted of these questions:

1. What is the extent of your use of minimum retroreflectivity values to monitor the performance of pavement markings?
 - 1A. What criteria are used to determine when a project qualifies for performance monitoring using minimum retroreflectivity values?
 - 1B. How do you identify and track which pavement segments are being monitored for the retroreflectivity values of the markings applied?
2. What is the initial retroreflectivity value applied to your pavement marking projects?
3. Has your agency established a minimum retained retroreflectivity value for a specified time period?
 - 3A. Does the required retained retroreflectivity value vary over time?
4. Please provide a link to your standard specification or special provision that identifies initial and retained retroreflectivity values for pavement markings. Send any file not available online to Chris Kline at chris.kline@ctcandassociates.com.
5. When is the initial retroreflectivity value taken?

6. How is the retained retroreflectivity of a pavement marking measured?
7. How often are performance inspections conducted?
8. Who conducts the inspections?
9. How do you track the results of performance inspections?
10. What is the process used when a pavement marking fails to meet minimum retroreflectivity requirements?
11. What successes have you experienced in applying retroreflectivity values to assess pavement marking performance?
12. What challenges have you experienced in applying retroreflectivity values to assess pavement marking performance?
13. Please use this space to provide any comments or additional information about your answers above.

We received responses from 12 state DOTs:

- Delaware.
- Georgia.
- Iowa.
- Kentucky.
- Minnesota.
- Missouri.
- Nebraska.
- New Hampshire.
- New York.
- North Carolina.
- Pennsylvania.
- South Dakota.

A respondent from Michigan DOT provided information about the agency's practices in lieu of completing the survey, noting that the agency does not apply minimum retroreflectivity values to field applications of established materials. (See page 14 of [Appendix A](#) for the information provided by Michigan DOT.) New York State DOT elected to respond to the survey, but the respondent indicated that the agency "does not officially require any minimum retroreflectivity values."

Three of the four state DOTs responding to the survey on warranty-based pavement marking programs—Alabama, Kansas and Oregon—provided information about those agencies' application of minimum retroreflectivity values. Where applicable, those survey responses are included below.

See [Appendix A](#) to this Preliminary Investigation for the full text of all survey responses.

The survey gathered information in seven topic areas related to the application of minimum retroreflectivity values for pavement markings:

- Retroreflectivity program description.
- Minimum retroreflectivity values.
- Measuring retroreflectivity.
- Performance inspections.
- Failure to meet retroreflectivity requirements.
- Successes.
- Challenges.

Few states responded to all questions in the survey, which resulted in findings that are quite limited in some areas. Key findings from the survey follow.

Retroreflectivity Program Description

Extent of the Retroreflectivity Program

In all but one state that responded (South Dakota), minimum retroreflectivity values are applied at the statewide level. South Dakota DOT checks retroreflectivity only for waterborne paint markings with high-grade polymer and for durable markings including epoxy, methyl methacrylate (MMA) and polyurea.

Identifying Pavement Markings for Performance Monitoring

Seven respondents described their agency's criteria for determining when a pavement marking is subject to performance monitoring. In four of these states (Georgia, Kentucky, Missouri and North Carolina), performance monitoring occurs on all projects; in Delaware, on all new construction. In South Dakota, performance monitoring is determined by the type of marking installed. In New York, monitoring is done for product approval only.

When asked how their agencies identify and track which pavement segments are being monitored, respondents provided the following:

- In Delaware, the contractor is responsible for submitting locations for testing once striping is completed.
- Kentucky Transportation Cabinet generates a relevant sample size for measuring various maintenance items, including striping retroreflectivity, through the agency's maintenance rating program.
- North Carolina DOT audits a percentage of roadways that provides the agency with a 95 percent confidence rating. The audit is conducted by a contractor using a mobile retroreflectometer.

Minimum Retroreflectivity Values

Some states have a single set of minimum initial retroreflectivity values for white and yellow markings, while others have different values for different marking products.

The table below summarizes survey responses. (Retroreflectivity levels are measured in units of millicandelas per square meter per lux, or $\text{mcd}/\text{m}^2/\text{lux}$.)

Respondents' Minimum Initial Retroreflectivity Values		
State	Unspecified Product	
	White ($\text{mcd}/\text{m}^2/\text{lux}$)	Yellow ($\text{mcd}/\text{m}^2/\text{lux}$)
Alabama	130	130
Iowa (wet)	150	100
Oregon	150	125
New Hampshire	200	150

Respondents' Minimum Initial Retroreflectivity Values		
State	Unspecified Product	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Kentucky, Missouri	300	225
Delaware	450	375
Iowa (regular)	550	325
State	Thermoplastic	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Minnesota (enhanced skid resistance)	250	150
Pennsylvania (cold)	250	200
Kansas	300	225
Pennsylvania (preformed)	300	250
Pennsylvania (hot)	300	250
Iowa (preformed)	325	150
North Carolina	375	250
Minnesota (preformed)	400	250
Nebraska (dry)	400	325
North Carolina (highly reflective elements)	700	700
State	Durable Markings	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Kansas (high-durability tape)	225	175
Iowa	300	200
South Dakota	331	206
State	Preformed Tape	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Georgia	600	400
Minnesota	600	500
State	Polyurea	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Nebraska (dry)	500	350
Georgia (longitudinal)	600	400
North Carolina	700	700

Respondents' Minimum Initial Retroreflectivity Values		
State	Epoxy	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Pennsylvania	250	200
Minnesota	300	200
Kansas (epoxy/multicomponent)	325	250
State	Waterborne	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Pennsylvania	250	165
Iowa (high-build)	300	225
State	Paint	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Minnesota	275	180
South Dakota (high-grade polymer)	350	275
State	Other	
	White (mcd/m²/lux)	Yellow (mcd/m²/lux)
Iowa (intersection)	150	100
Kansas (cold plastic)	250	175
Kansas (pattern cold plastic)	500	300
Iowa (profiled)	700	350

A few respondents offered additional comments about their application of minimum retroreflectivity values:

- In Georgia, the DOT uses high-build paint for roadways of 8,000 or less average daily traffic. The required retroreflectivity values for these roadways are lower than for interstate routes.
- Missouri DOT is considering increasing its minimum values of 300 mcd/m²/lux for white markings and 225 mcd/m²/lux for yellow markings.
- In North Carolina, minimum specifications for thermoplastic pavement markings with highly reflective elements that are now at 700/700 mcd/m²/lux for white/yellow markings had been 800/500 mcd/m²/lux for white/yellow markings.

When Initial Retroreflectivity Values Are Taken

The time spans reported by respondents for assessing the initial retroreflectivity of a new pavement marking ranged from the immediate testing conducted by Alabama DOT to the 45 days reported by Missouri and Minnesota DOTs as the last day for a measurement. A 30-day measurement period was most common.

The table below summarizes survey responses.

Respondents' Timing of Initial Retroreflectivity Measurements	
Timing of Retroreflectivity Measurement After Installation	State
Immediately after installation	Alabama
Between 12 hours and 14 days	Kansas
Within two days of project acceptance	Oregon
Between two and 30 days	Nebraska, South Dakota
Between seven and 14 days (typically); no longer than 45 days	Missouri
Between seven and 35 days	Iowa
Between 14 and 45 days	Minnesota
Within 21 days	Pennsylvania
Within 30 days	Delaware, New Hampshire, North Carolina <i>Georgia</i> . Contractors are required to obtain retroreflectivity readings within the first 30 days and again at 180 days for acceptance.

Minimum Period for Retained Retroreflectivity Values

Only three respondents reported practices that apply a minimum retained retroreflectivity value for a specified time period. Two states—Georgia and Nebraska—have established a 180-day observation period for final project acceptance, during which the marking should not go below the required performance values.

In Pennsylvania, all pavement markings are applied on the agency's National Transportation Product Evaluation Program (NTPEP) test deck before receiving approval for use. The agency has established minimum retroreflectivity values for test deck applications that must be met for up to three years depending on the type of marking.

Retained Retroreflectivity Values Over Time

Of the respondents addressing the possibility of required retained retroreflectivity values varying over time, only one state—Pennsylvania—reported lowering the minimum requirement each year. Seven states—Alabama, Georgia, Kansas, Kentucky, Missouri, Oregon and South Dakota—do not include such variances for retained retroreflectivity in their specifications.

Measuring Retained Retroreflectivity

Most respondents measure the retained retroreflectivity of pavement markings with the use of a 30-meter retroreflectometer. In Iowa, measurements can be taken using a handheld

retroreflectometer and a mobile retroreflectometer mounted on a van. Three states—Delaware, New York and South Dakota—do not measure retained retroreflectivity.

Some respondents provided information about the specifications guiding their measurement practices or the instruments they use:

- The Iowa DOT respondent highlighted a specification (see “Determining Retroreflectivity of Durable Pavement Markings,” available at <http://www.iowadot.gov/erl/current/IM/content/386.htm>) that describes the measurement process for both handheld and mobile measurement practices and provides sample reports used to record results.
- The Oregon DOT respondent identified the specific handheld meter used by the agency—the Delta LTL-X retroreflectometer.
- The Pennsylvania DOT respondent noted that the retroreflectometer used by the agency conforms to the ASTM E1710-11 standard (Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer; see <http://www.astm.org/Standards/E1710.htm>).

Other respondents reported these measurement practices:

- Kansas DOT takes retroreflectivity readings every mile, with five readings per line every mile. The respondent did not specify how the measurements are taken.
- Minnesota DOT districts can submit requests to measure sections of markings that crews have identified as possibly reaching the agency’s threshold for replacement (100 mcd/m²/lux for white markings and 80 mcd/m²/lux for yellow markings).
- In Missouri, the DOT’s crews assess retroreflectivity values with a handheld retroreflectometer or nighttime visual inspections to identify pavement segments that can be excluded from the agency’s annual striping program.

Performance Inspections

Respondents offered little consensus on the conduct of performance inspections. While inspections are not conducted in Iowa and New Hampshire, annual inspections are conducted in Missouri and Nebraska.

Missouri DOT crews conduct inspections on all routes using nighttime visual assessments and/or handheld meter readings. The agency applies minimum retroreflectivity levels of 200 mcd/m²/lux for white markings and 175 mcd/m²/lux for yellow markings, with 150 mcd/m²/lux and 125 mcd/m²/lux as the failure point for white and yellow markings, respectively. A research study conducted for the agency many years ago identified these minimum levels.

In Pennsylvania, performance inspections are conducted before a product is approved for use. Inspections are conducted on the agency’s test deck once a month for the first six months and then quarterly thereafter for up to three years, depending on the type of marking.

Other respondents reported a less formalized inspection process:

- Georgia DOT conducts random inspections within the first 30 days or within the first six months of an installation.
- In Minnesota, district maintenance staff make regular visual assessments during daytime and nighttime hours. Actual retroreflectivity measurements are taken upon staff request.

Responsibility for Inspections

More than half of the agencies responding to a survey question about the responsibility for conducting performance inspections conduct those inspections with agency staff. The table below summarizes survey responses.

Responsibility for Conducting Performance Inspections	
Responsible Party	State
Agency staff	Delaware, Georgia, Minnesota, Nebraska, New Hampshire
Agency staff with contractor assistance	New York, North Carolina
Third-party contractor*	Missouri

- * The agency retains a third-party contractor that conducts mobile retroreflectivity readings for contract-installed pavement markings. The contractor also conducts random quality assurance readings to assist the agency in evaluating its overall pavement marking program.

Tracking Inspection Results

Respondents provided relatively little detail about their practices for tracking inspection results. A spreadsheet is used by Delaware, Nebraska and Pennsylvania DOTs to track results. Pennsylvania DOT goes beyond maintaining its own spreadsheet, entering inspection data on the NTPEP DataMine 2.0 web site (see <http://data.ntpep.org/>); project data is also noted in the PennDOT inspector's journal.

North Carolina DOT tracks inspection results centrally, while in Minnesota districts keep track of pavement marking quality and replacement plans. Iowa and New York State DOTs do not track inspection results.

Failure to Meet Retroreflectivity Requirements

When a pavement marking fails to meet the agency's minimum retroreflectivity requirements, most respondents require the contractor to remove and replace the marking. Ten of the 13 respondents addressing this question apply this practice, either exclusively or as an option in a suite of remedies. Five states—Iowa, Kansas, Minnesota, Missouri and North Carolina—consider a pay reduction associated with acceptance of a marking installation that fails to meet minimum retroreflectivity requirements. Minnesota DOT described an ongoing examination of marking performance that schedules failing markings for “refreshing.”

The table below summarizes survey responses.

Respondents' Practices When Markings Fail to Meet Minimum Requirements		
Practice	Agency	Comment
Require contractor to "correct the work"	Georgia	N/A
Require contractor to remove and replace marking	Delaware, Iowa, Kansas, Minnesota, Missouri, Nebraska, New Hampshire, North Carolina, Pennsylvania, South Dakota	<i>Minnesota.</i> The contractor must replace the marking if it is failing by more than 20 percent. <i>Missouri.</i> There is a minimum threshold below which replacement is required. <i>North Carolina.</i> The agency may apply a pay deduction or direct the contractor to remove and replace.
Pay reduction to contractor	Iowa, Kansas, Minnesota, Missouri, North Carolina	<i>Iowa.</i> Markings that are low on initial retroreflectivity up to 20 percent may, at the discretion of the agency, be accepted with a price adjustment. <i>Minnesota.</i> The contractor is subject to a deduction if the marking fails by less than 20 percent. <i>Missouri.</i> If the line falls below the minimum threshold for replacement, there is a percent deduction for each level below, or the contractor may choose to fix the deficient sections for full payment. <i>North Carolina.</i> The agency may apply a pay deduction or direct the contractor to remove and replace.
Ongoing agency assessment of failure	Minnesota	Once a marking is nearing the minimum values of 100 mcd/m ² /lux for white markings and 80 mcd/m ² /lux for yellow markings, the district will schedule it for refreshing. The agency maintains its own pavement marking crews that work full-time during the construction season refreshing markings across the state.

Successes

When asked about program successes, several respondents noted that the application of minimum retroreflectivity values has improved vendor performance or the quality of the markings:

- Georgia DOT collaborated with contractors and manufacturers to develop test decks and establish minimum values that are achievable but permit the agency to retain a high performance standard.
- In Minnesota, pavement marking quality has increased as contractors have responded with increased compliance with the agency's mobile retroreflectometer measurement program.
- Contractors in New Hampshire appear to exhibit greater responsibility when it is understood that minimum values must be met to receive payment.

In similar comments, the Pennsylvania DOT respondent noted that the use of minimum retroreflectivity values “helps get the best possible markings on the highway.” In Iowa, the quality and durability of the pavement markings has improved, and the Delaware DOT respondent noted that use of minimum values has resulted in greater consistency in line quality.

In addition to the more general comments provided by other respondents, the Missouri DOT respondent offered a solution to a specific inspection problem. Previously, when the agency used a double drop wet element to achieve wet nighttime performance, there was no efficient way to check wet nighttime performance and no specification other than the application rate with which to measure the installation. With a move to ASTM Type III beads, the agency has found that acceptable dry readings provide a high confidence level of the adequacy of the wet nighttime performance.

Challenges

Respondents reported a range of challenges associated with marking installation, performance monitoring and contractors.

Installation

- Minnesota DOT struggles with applying pavement markings to pavement preservation projects that have surfaces such as seal coats or fog-sealed surfaces.

Performance Monitoring

- In Delaware, winter weather presents one of the agency’s primary challenges. When markings are applied in the fall, sometimes the markings will be damaged by a snowplow before they can be given a fair evaluation.
- In Iowa and Nebraska, the number of markings to track presents challenges.
- Since project acceptance and contractor payment is primarily based on retroreflectivity values, a thin paint that holds just enough beads to meet initial reading requirements but fails quickly can result in full payment to the contractor. Missouri DOT is considering raising minimum values and training inspectors on what to look for to reduce this type of occurrence.

Contractor-Related Issues

- Some contractors in Minnesota contend that the DOT’s values are too high to reach, especially on rumble strips.
- The New Hampshire DOT respondent reported challenges in getting contractors to accept failed results.
- North Carolina DOT reports challenges with contractors not meeting minimum retroreflectivity levels or not using the correct drop rate.
- In Pennsylvania, it has been challenging to get the contractor to duplicate the performance of a marking observed on the test deck in actual application on the highway.

Specifications, Special Provisions and Related Documents

Specifications, special provisions and other documents related to survey respondents' warranty and retroreflectivity monitoring programs are highlighted below; also included are publications from a few states not responding to the survey.

Below are publications associated with the following state DOTs:

- Alabama.
- Florida.
- Georgia.
- Indiana.
- Iowa.
- Kansas.
- Kentucky.
- Minnesota.
- Missouri.
- Nebraska.
- New Hampshire.
- North Carolina.
- Oregon.
- Pennsylvania.
- Virginia.
- West Virginia.

Many of the documents cited below also appear in the survey results presented in [Appendix A](#).

Alabama

Permanent Traffic Marking Materials and Producers, List V-4, Permanent Traffic Marking, Alabama DOT, February 2016.

<http://www.dot.state.al.us/mtweb/Testing/MSDSAR/doc/QMSD/Lv04.pdf>

See page 6 of this document for the warranty specifications for traffic marking materials.

Florida

Section 710, Painted Pavement Markings, Standard Specifications, Florida DOT, 2013.

<http://www.dot.state.fl.us/specificationsoffice/Implemented/SpecBooks/2013/Files/710-2013.pdf>

Excerpt from the Standard Specifications:

710-4.3 Retroreflectivity: Apply white and yellow standard pavement markings that will attain an initial retroreflectance of not less than 300 mcd/lx·m² and not less than 250 mcd/lx·m², respectively. Measure, record and certify on a Department approved form and submit to the Engineer, the retroreflectivity of white and yellow pavement markings in accordance with FM 5- 541.

The Department reserves the right to test the markings within 3 days of receipt of the Contractor's certification. Failure to afford the Department opportunity to test the markings will result in non-payment. The test readings should be representative of the Contractor's striping performance. If the retroreflectivity values measure below values shown above, reapply the striping at no additional cost to the Department.

For standard pavement markings, ensure that the minimum retroreflectance of white and yellow pavement markings are not less than 150 mcd/lx m². If the retroreflectivity values fall below the 150 mcd/lx m² value within six months of initial application, the striping will be reapplied at the Contractor's expense.

Georgia

Section 657, Preformed Plastic Pavement Markings, Special Provisions, Georgia DOT, October 2012.

http://www.dot.ga.gov/PartnerSmart/Business/Source/special_provisions/shelf/sp657.pdf

In addition to addressing the agency's retroreflectivity requirements, this special provision includes Section 657.3.07, Contractor Warranty and Maintenance (see page 9 of the PDF), which includes provisions for the only warranty the agency applies to its pavement markings.

Indiana

Measurement of Retro-Reflective Pavement Marking Materials, ITM No. 931-15T, Office of Materials Management, Indiana DOT, November 2015.

http://www.in.gov/indot/div/mt/itm/pubs/931_testing.pdf

Excerpt from the scope:

1.1 This test method covers the measurement and acceptance of retro-reflectivity on pavement markings using portable hand-operated and mobile 30-meter geometry instruments.

1.2 The purpose of this test method is to assure that adequate retro-reflectivity of pavement markings is provided by newly applied markings for the driver of a vehicle and to assure that the retro-reflectivity is maintained throughout the warranty period.

Iowa

Section 2527, Pavement Marking, Standard Specifications, Iowa DOT, 2015.

<http://www.iowadot.gov/erl/current/GS/content/2527.htm>

This specification describes the materials and construction requirements associated with the agency's pavement marking installations.

Section 4183, Traffic Paints and Pavement Markings, Standard Specifications, Iowa DOT, 2015.

<http://www.iowadot.gov/erl/current/GS/content/4183.htm>

This specification provides formulation guides for paint, field service requirements, and testing and acceptance for pavement marking tape and two types of fast-dry traffic paint—volatile organic compound-compliant solvent borne paint and waterborne paint.

Determining Retroreflectivity of Durable Pavement Markings, Instructional Memorandum 386, Iowa DOT, undated.

<http://www.iowadot.gov/erl/current/IM/content/386.htm>

This document describes the testing required for final acceptance of pavement marking installations and includes sample forms.

Survey on Pavement Marking Practices, Iowa DOT Pavement Marking Task Force, Center for Transportation Research and Education, June 2007.

<http://scote.transportation.org/Documents/survey-070307-markings-nrh.pdf>

While somewhat dated, this document presents results of a survey of state DOTs conducted for Iowa DOT that addressed pavement marking performance. Twenty-three states responded to this question:

Does your state use a performance specification for the installation of waterborne or durable pavement markings? If so, does this specification, or other criteria such as minimum initial retroreflectivity, apply to contractors, state crews, or both?

Kansas

Section 806, Durable Pavement Marking, Standard Specifications, Kansas DOT, 2015.

<http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burConsMain/specprov/2015/806.pdf>

This specification addresses the agency's retroreflectivity requirements but does not include warranty-related provisions.

Kentucky

Section 713, Permanent Pavement Striping, Standard Specifications for Road and Bridge Construction (June 2014 Supplemental Specifications Included), Kentucky Transportation Cabinet, 2012/2014.

<http://transportation.ky.gov/Construction/StdSpecsWSupplSpecs/2012%20Standard%20Spec%20with%20Supp%20Spec%20June%202014.pdf>

Section 713 begins on page 415 of the PDF and includes the agency's retroreflectivity requirements.

Minnesota

Section 2582, Pavement Markings, Standard Specifications for Construction, Minnesota DOT, 2016.

<http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf>

Section 2582 begins on page 530 of the PDF and includes the agency's retroreflectivity requirements.

Missouri

Category: 620 Pavement Marking, Engineering Policy Guide, Missouri DOT, July 2015.

http://epg.modot.org/index.php?title=Category:620_Pavement_Marking

This section of the policy guide provides pavement marking guidelines for contractors and the agency.

Category: 620.12 Construction Inspection for Sec 620, Engineering Policy Guide, Missouri DOT, February 2015.

http://epg.modot.org/index.php?title=620.12_Construction_Inspection_for_Sec_620

This specification provides the agency's construction requirements for various types of pavement markings.

Category: 620.13 Measurement of Retroreflectivity by Handheld Retroreflectometers, Engineering Policy Guide, Missouri DOT, February 2015.

http://epg.modot.org/index.php?title=620.13_Measurement_of_Retroreflectivity_by_Handheld_Retroreflectometers

These guidelines "are based on MoDOT Test Method T80 and ASTM D7585-10. These guidelines are to be used by MoDOT forces when determining the quality and remaining life of MoDOT pavement markings, both existing and newly applied."

Related Resource:

Test Method MoDOT T80, Measurement of Retroreflectivity by Handheld Retroreflectometers, Missouri DOT, undated.

http://epg.modot.org/files/d/db/620.10_MoDOT_T80.pdf

This test method suggests the type of equipment to be used for the measurement of retroreflectivity and the procedure for sampling,

Nebraska

D-15-1013, Wet Reflective Thermoplastic Pavement Marking, Grooved, Special Provisions, Nebraska Department of Roads, May 2011.

See [Appendix B](#).

This special provision addresses application and retroreflectivity requirements, the observation period, and the basis for payment for retroreflective thermoplastic pavement markings.

D-17-1013, Wet Reflective Polyurea Pavement Marking, Grooved, Special Provisions, Nebraska Department of Roads, January 2013.

See [Appendix C](#).

This special provision addresses application and retroreflectivity requirements, the observation period, and the basis for payment for retroreflective polyurea pavement markings.

New Hampshire

Section 632, Retroreflective Pavement Markings, Standard Specifications, New Hampshire DOT, 2016.

<http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2016NHDOTSpecBookWeb.pdf>

Section 632 begins on page 400 of the PDF and provides the agency's guidance on the use of retroreflective markings.

North Carolina

Division 12, Pavement Markings, Markers and Delineation, Standard Specifications for Roads and Structures, North Carolina DOT, January 2012.

<https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Roadway%20Standard%20Specifications%20Division%2012%20-%20Pavement%20Markings,%20Markers%20and%20Delineation.pdf>

This is the agency's specification related to pavement markings.

Thermoplastic Pavement Marking Material, (HRE), Project Special Provision, North Carolina DOT, January 2016.

[https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Thermoplastic Pavement Marking Material \(HRE\) Website.pdf](https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Thermoplastic%20Pavement%20Marking%20Material%20(HRE)%20Website.pdf)

This special provision describes the minimum retroreflectivity values, measurement and payment for the agency's thermoplastic pavement marking material.

Signing and Delineation, North Carolina DOT, undated.

<https://connect.ncdot.gov/resources/safety/Pages/Signing-and-Delineation.aspx>

This web page includes information and resources applicable to pavement marking, including specifications, special provisions and layouts.

Oregon

Section 00850, Common Provisions for Pavement Markings, Part 00800, Permanent Traffic Safety and Guidance Devices, Oregon Standard Specifications for Construction, Oregon DOT, 2015.

http://www.oregon.gov/ODOT/HWY/SPECS/docs/15book/15_00800.pdf

Section 00850, which begins on page 22 of the publication (page 26 of the PDF), includes these subsections of particular interest:

- Specifications for longitudinal durable markings—see page 35 of the publication (page 39 of the PDF).
- Specifications for longitudinal high-performance markings—see page 37 of the publication (page 41 of the PDF).
- Specifications for transverse bars and legends—see page 40 of the publication (page 44 of the PDF).

Section 00170.85(c)(1), Responsibility for Defective Work, Part 00100, General Conditions, Oregon Standard Specifications for Construction, Oregon DOT, 2015.

http://www.oregon.gov/ODOT/HWY/SPECS/docs/15book/15_00100.pdf#page=84

Page 80 of the publication (page 84 of the PDF) addresses general requirements for manufacturer warranties and guarantees.

ODOT TM 777: Method of Test for Evaluation of Retroreflectivity of Durable and High Performance Pavement Markings Using Portable Hand-Operated Instrument, Manual of Field Test Procedures, Oregon DOT, 2015.

ftp://ftp.odot.state.or.us/techserv/construction/TrainingManuals/MFTP/2015/03_ODOT_test_methods.pdf

Test Method 777, which begins on page 147 of the PDF, is used to test the dry retroreflectivity of durable and high-performance pavement markings using portable hand-operated instruments.

Procedure for Notification and Repair of High Performance and Durable Pavement Marking Warranty Projects, Oregon DOT, August 2009.

https://www.oregon.gov/ODOT/HWY/CONSTRUCTION/qpl/docs/pavement_markings_warranty_procedure.pdf

This one-page document outlines the responsibilities and expectations of the agency, manufacturer and contractor with regard to repair of pavement markings under warranty.

Pennsylvania

Publication 408/2016, Construction Specifications, Pennsylvania DOT, 2016.

http://www.dot.state.pa.us/public/PubsForms/Publications/Pub_408/408_2016/408_2016_IE/408_2016_IE.pdf

Sections of the agency's Construction Specifications that relate to pavement marking include:

- Section 960, Hot Thermoplastic Pavement Markings—see page 690 of the PDF.
- Section 961, Cold Plastic Pavement Markings or Legends—see page 692 of the PDF.
- Section 962, Waterborne Pavement Markings—see page 693 of the PDF.
- Section 964, Epoxy Pavement Markings—see page 697 of the PDF.
- Section 965, Preformed Thermoplastic Pavement Markings—see page 700 of the PDF.

PA Test Method No. 431, Pavement Marking Sampling of Longitudinal and Transverse Lines, Legends and Symbols for Retroreflectometer Testing, Publication 19, Field and Laboratory Testing Manual, Pennsylvania DOT, October 2013.

http://www.dot.state.pa.us/public/pdf/BOCM_MTD_LAB/PUBLICATIONS/PUB_19/PTM-431.pdf

From the purpose:

This method describes the procedure used to determine where pavement marking retroreflectometer measurements will be taken for longitudinal and transverse lines, legends, and symbols. The retroreflectometer test values for these materials at these locations are compared to the specification requirements to determine acceptable or unacceptable performance.

Durable Pavement Markings, Test Deck Specification, Pennsylvania DOT, February 2009.

See [Appendix D](#).

From the scope:

This specification covers the evaluation of the following retroreflective durable pavement marking materials that are applied on the National Transportation Product Evaluation Program (NTPEP) test deck conducted in Pennsylvania:

- Epoxy
- Cold Plastic
- Methyl-Methacrylate (MMA)
- Hot Thermoplastic
- Preformed Thermoplastic
- Polyester
- Polyurea
- Other Types – as recommended by the manufacturer unless specified by the Department

Specification for Waterborne Traffic Line Paint, Pennsylvania DOT, September 2015.

See [Appendix E](#).

This specification addresses the agency's use of fast-drying waterborne traffic line paints on bituminous and Portland cement concrete pavements.

Virginia

Special Provision for Type B, Class VI Pavement Line Marking Tape, Plant Mix Schedules (Volume 2 of 2), Special Provision Copied Notes, Special Provisions and Supplemental Specifications for Plant Mix Schedules—Statewide, Virginia DOT, July 2015.

http://www.virginiadot.org/business/resources/const/Announce_VOL2_2016_F_PlantMix.pdf

This special provision, which begins on page 279 of the publication (page 283 of the PDF), addresses initial approval, retroreflectivity requirements, installation, post-installation evaluation, requirements under the warranty, measurement and payment. Other provisions not subject to warranty but addressing retroreflectivity appear on page 260 (page 264 of the PDF) and page 283 of the publication (page 287 of the PDF).

Type B, Class VI Pavement Markings, Traffic Engineering Division Memorandum, Virginia DOT, September 2011.

http://www.virginiadot.org/business/resources/traffic_engineering/memos/261.1_TypeB_ClassVI_Pavement_Markings.pdf.

From the memorandum:

The Department is revising its policy on the use of Type B, Class VI pavement markings to increase flexibility and reduce constructability concerns. This memorandum outlines areas where Type B, Class VI markings shall be used and areas where they may be used subject to engineering judgment. This clarification is effective for projects to be issued for advertisement on or after December 1, 2014. Projects being assembled for bid should utilize the revised Policy effective immediately. Exception is permitted if quantities and estimates are already completed and bid advertised is scheduled prior to December 2014.

Section 103, Award and Execution of Contracts, Road and Bridge Specifications, Virginia DOT, 2016.

http://www.virginiadot.org/business/resources/const/Specs_CombinedBook.pdf

See page 25 of the document for Section 103, which addresses bonds.

West Virginia

Special Provision for the Interstate/Appalachian Pavement Marking Contract (Template), Division of Highways, West Virginia DOT, February 2011.

http://www.transportation.wv.gov/highways/contractadmin/specifications/SpecComit/SpecMeetings/specmeetyear/2011/Documents/20110214_PDFs/711_20110204_RLS_711%2043WetReflectiveTypeX_SProj.pdf

This template contract addresses the agency's requirements in connection with its warranty and also addresses retroreflectivity requirements for pavement markings.

Related Resources

A sampling of publications in the following four categories offers additional perspective on some of the issues addressed in survey responses:

- Pavement marking warranties.
- Measuring retroreflectivity: General guidance.
- Measuring retroreflectivity: State practices.
- Test decks.

Pavement Marking Warranties

National Guidance

NCHRP Synthesis 408: Pavement Marking Warranty Specifications, Michael J. Markow, 2010.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_408.pdf

Researchers examined warranty-related practices in North America and Europe with the use of a literature review, a survey of U.S. and Canadian transportation agencies, and interviews with contractors and suppliers. The “experience and assessments of the 23 agencies that now use pavement marking warranties” provided the basis for a wide range of findings. Chapter 4, Conclusions, which begins on page 39 of the report (page 48 of the PDF), provides an overview of findings, summarizes the perceived benefits of warranties and reasons for not using them, and identifies gaps in knowledge that suggest the need for further research.

State Practices

Alaska and Tennessee

Pavement Marking Demonstration Projects: State of Alaska and State of Tennessee, Office of Safety Research and Development, Federal Highway Administration, November 2013. <https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/12048/12048.pdf> Chapter 6, State Bidding and Procurement, begins on page 135 of the document (page 153 of the PDF) and includes a discussion of performance-based pavement marking specifications. An excerpt from the chapter summary on page 148 of the report (page 166 of the PDF):

There is no research that conclusively demonstrates that a move to performance- or warranty-based specifications for the procurement of pavement markings will result in higher-quality installations. In fact, as evidenced by reviewing recent surveys of State agencies, there is a wide disparity in how agencies are procuring pavement markings. This is perhaps influenced by the lack of a national standard for basic pavement marking performance, such as retroreflectivity.

However, the surveys show some important trends and information. First, many States are implementing, or at least experimenting with, performance- or warranty-based specifications. It is reasonable to assume that in a time of significant fiscal constraints, this trend represents an underlying belief that the pavement marking procurement process can be improved by moving to a different type of specification. Furthermore, responses from the surveys indicate that many of the agencies investigating these types of specifications are doing so to obtain

higher quality, longer life cycles, increased durability, and a reduction in administrative costs such as inspections.

....

One important obstacle to the utilization of performance-based specifications is the lack of true maintenance responsibility geared to the overall performance of the product or installation. Most installations are performed by local and small contractors that prefer component specifications rather than a performance-based approach. Bundling pavement marking installation with other road services, such as routine maintenance or pavement rehabilitation, is a viable alternative for the utilization of performance-based specifications; however, this type of contract may be attractive only to large contracting firms.

Colorado

Cost-Benefit Evaluation of Enhanced Specifications for Epoxy Pavement Marking Material, Jay Goldbaum, Colorado DOT, January 2010.

<https://www.codot.gov/programs/research/experimentalfeatures/epoxypavementmarking.pdf>

The project's objective, as described on page 6:

The objective of this research is to evaluate the cost-effectiveness of using enhanced specifications with selected performance measures on a few pilot projects. Groups other than CDOT have studied various pavement markings with the goal of determining which is more cost-effective. However, these studies were not performed in Colorado. Therefore, their results may not be applicable because of different weather conditions, traffic volumes, pavement surface types and installation procedures. The Task Force recommended constructing four pilot projects. Two projects were constructed with a two-year warranty specification. The warranty specification can be found in Appendix A. Two projects were constructed with an incentive/disincentive specification. The incentive/disincentive specification can be found in Appendix B.

Missouri

Evaluation of 3M Tape vs. Poly-Carb Striping and Striping Warranty, John D. Wenzlick and James Brocksmith, Missouri DOT, December 2009.

<http://library.modot.mo.gov/RDT/reports/Rd09019/or10012.pdf>

From the abstract:

The objective of this study was to find the best, most highly visible and long lasting striping for Missouri's major highways. The Missouri Department of Transportation (MoDOT) currently has a contract with the 3M Company for the installation of Preformed Pavement Marking Tape for longitudinal striping on divided major roads but the contract will be ending in 2011. Tape has been found to be one of the best wet-reflective pavement markings so far but costs up to \$5 per linear foot. The contract being studied was awarded on July 23, 2008 to Poly-Carb Inc. to provide Striping and a Striping Warranty on 235 linear miles of longitudinal striping on various roadways in the St. Louis and Kansas City areas. The way the whole process was done was innovative. It was a performance based warranty contract. Rather than specifying certain materials, the Department went out with a Request for Bids (RFB) that listed the requirements of how the stripe was to perform and let the bidders propose how they would meet those requirements. Asking for a four-year warranty was also something new for MoDOT. While there is a four-year warranty with 3M, this was the first time to ask for a warranty on pavement markings using a bidding process and specifying a payment schedule linked to that warranty. The Striping Warranty will be in effect until June 30, 2013. The contractor put down about 2.9 million feet or 550 line miles of the product.

The final cost of the contract was \$6.56 million, making the cost per linear foot \$2.37 compared to the current \$5 per linear foot for Preformed Pavement Marking Tape. Initial inspection results were very good with good color and very high retroreflectivity readings and initial payments were made with no corrections needed to the markings. Performance measures will be watched closely for the next four years. This study will evaluate both the quality of the pavement marking and the effectiveness of the performance based warranty to lower costs.

Utah

Lessons Learned - Pavement Marking Warranty Contract, Milan Zlatkovic and Richard J. Porter, Utah DOT, December 2013.

http://ntl.bts.gov/lib/51000/51100/51140/UT-13_16.pdf

From the abstract:

In 2012, Utah Department of Transportation (UDOT) implemented a performance-based warranty on a portion of an I-15 pavement marking project. The awarded contract requested a contractor warranty on the implemented markings for a total duration of six years. This is the first time that UDOT has requested a warranty on pavement markings, and also the first time that Interstate Maintenance (IM) funds were used for pavement markings. This report documents lessons learned from the preconstruction, construction and post-construction phases of this project, collected through surveys of key involved UDOT personnel. It also includes a literature review on pavement marking warranty contracts in general, a review of the I-15 performance-based warranty contract, and reviews of previous, materials and workmanship warranty based pavement marking contracts of similar size. The estimated life-cycle and suggestions for benefit-cost analysis are also included.

Measuring Retroreflectivity: General Guidance

Project in Progress: Pavement Marking Presence Tool, Partnership to Enhance General Aviation Safety, Accessibility and Sustainability, Federal Aviation Administration, expected completion date: December 2016.

Project Summary at <https://www.pegasas.aero/projects.php?p=10>

Excerpt from the Project Summary:

This research project has two objectives. The first objective is to develop a mobile (smart phone) tool to allow users the ability to assess the existing pavement marking presence (the amount of pavement marking on the pavement surface) and also help with quality assurance of newly installed pavement marking products that are not made up of a continuous solid line (MMA splatter pattern is one example). The second objective is to develop an easy to use tool that inspectors can use to assess retroreflectivity and color using their smart phone or tablet.

NCHRP Report 743: Predicting the Initial Retroreflectivity of Pavement Markings from Glass Bead Quality, Omar Smadi, Neal Hawkins, Basak Aldemir-Bektas, Paul Carlson, Adam Pike and Chris Davies, 2013.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_743.pdf

Excerpt from the abstract:

This report describes a proposed laboratory test method to predict the initial retroreflectivity of pavement markings in the field based on the quality of the applied glass beads. Thus, the report will be of immediate interest to state materials and maintenance engineers with responsibility for specification and placement of pavement marking materials. The project

team conducted a combined laboratory and field experiment to develop, verify, and validate the proposed test method.

“Development of a Pavement Marking Condition Index from Retroreflectivity and Presence Measurements,” Carmine E. Dwyer, William R. Vavrik, Michael J. Harrell and Rachel L. Reinicke, *TRB 91st Annual Meeting Compendium of Papers DVD*, Paper #12-4265, 2012.

Citation at <http://trid.trb.org/view/2012/C/1130780>

From the abstract:

To prepare for the impending amendment to the Manual on Uniform Traffic Control Devices (MUTCD) to set minimum retroreflectivity levels for pavement markings, many transportation agencies have been monitoring marking retroreflectivity performance to determine marking service life and therefore life cycle costs. Another important metric when evaluating marking performance is the marking’s “presence,” or how well the marking resists abrasion and remains bonded to the pavement surface. ASTM D913-10 Standard Practice for Evaluating Degree of Traffic Paint Line Wear describes a subjective method for comparing photographic references to estimate marking presence. However, a more quantitative method of monitoring marking presence has been accomplished by collecting photos of markings and then processing the photos through an image analysis program that reports the marking’s presence as a calculated percentage. Retroreflectivity and presence data can be evaluated together for developing life cycle performance curves or for determining annual re-stripping efforts. However, combining the two metrics can be subjective if there isn’t a standard process for combining them. To standardize the process and eliminate subjectivity, Applied Research Associates, Inc. (ARA) developed a Marking Condition Index (MCI). This paper briefly describes the two performance measures and details the development of the MCI.

“Evaluation of Retroreflectivity Measurement Techniques for Profiled and Rumble Stripe Pavement Markings,” Adam M. Pike, Lance D. Ballard and Paul J. Carlson, *Transportation Research Record 2258*, pages 80-87, 2011.

Citation at <http://dx.doi.org/10.3141/2258-10>

From the abstract:

The objectives of this research were to evaluate the influence of stepping distance on average, dry retroreflectivity measurements of profiled and rumble stripe pavement markings through the use of a portable (handheld) retroreflectometer and to compare these measurements with ones made with a mobile retroreflectometer. The retroreflectivity of flat, profiled, and rumble stripe thermoplastic pavement markings was evaluated by several means with the use of multiple handheld retroreflectometers and a mobile retroreflectometer. Stepping distance was found to have no practical influence on averaged retroreflectivity measurements of evaluated marking types when measured in accordance with ASTM E 1710-05. The addition of an extended base on the handheld retroreflectometer, the hand-leveling of the device, or both were suitable ways to maintain the retroreflectometer in the plane defined by the tops of the pavement marking profiles for proper measurement. The vertical structure of the profiled and rumble stripe pavement markings did not increase the dry retroreflectivity measurements of the markings. The flat segments between the depressions of the rumble stripe pavement marking were found to produce the highest retroreflectivity readings of any part of the rumble stripe. A properly calibrated, mobile retroreflectometer operated by an experienced user gave dry retroreflectivity measurements that were not practically different from those obtained with a handheld retroreflectometer in accordance with ASTM E 1710-05. These findings validated

the capability of the handheld retroreflectometer to accurately measure profiled and rumble stripe pavement markings.

Measuring Retroreflectivity: State Practices

Arkansas

Establishing a Statewide Pavement Markings Management System, Ron Strickland, Arkansas State Highway and Transportation Department, March 2007.

<http://www.arkansastrc.com/TRC%20REPORTS/TRC%200403.pdf>

From the abstract:

The Arkansas State Highway and Transportation Department currently relies on visual inspection for managing pavement marking condition and replacement. The Department currently has no database for the systematic monitoring or scheduling of maintenance or replacement of pavement marking retroreflective luminescence (RL) levels on a statewide basis. Depending on the measures necessary to meet pending FHWA compliance regarding RL levels: 1. The Department should consider including specifications regarding minimum RL levels for new installations and warranty periods (as measured by 30-meter geometry); 2. The Department should hold manufacturers and contractors to task to meet contract specifications for both temporary and permanent pavement markings; and 3. The Department should have available the means and equipment required to perform the work necessary for determining new installation and warranty compliance. The Department should formulate a systematic statewide method for collecting and evaluating data on both new and existing pavement striping, such that the Department can adequately provide for continued public safety by: 4. Determining statewide needs to effectively plan for meeting anticipated compliance levels by means of a database system containing all relevant data for evaluating highway RL levels; 5. Managing a scheduled monitoring and maintenance program within a statewide budget; 6. Effectively evaluating pavement marking products that exhibit superior performance with regards to a range of durability factors; and 7. Matching pavement striping to road surface characteristics and conditions to achieve the greatest costs benefits. A database containing simply RL information is not adequate for developing an effective pavement marking management system. All relevant factors impacting the serviceability and durability of pavement markings must be included in order to make comprehensive decisions regarding the management and placement of pavement markings.

Florida

“Precision Study on Handheld Retroreflectometers for Measurement of Pavement Markings,” Guangming Wang, Joshua Sevearance, Charles Holzschuher, Bouzid Choubane and James Fletcher, *TRB 95th Annual Meeting Compendium of Papers*, Paper #16-2870, 2016.

Citation at <https://trid.trb.org/view/2016/C/1393082>

From the abstract:

The Florida Department of Transportation (FDOT) has historically used the handheld retroreflectometers to evaluate the retroreflectivity of pavement markings. However, the precision of handheld devices used as the reference to FDOT’s mobile retroreflectivity unit (MRU) program has not been fully documented. As with any testing, the major concerns of the end usefulness of the resulting data are accuracy and precision. Although a level of uncertainty is always inherent to any measurement process, it must also be appropriately quantified or assessed. Therefore, FDOT initiated the present study to assess the level of precision of the handheld retroreflectometers. A description of the testing program, the data

collection effort, and the subsequent analyses and findings are presented. Nine 1.0-mi-long field sites were selected with more than 5,000 measurements collected by two handheld retroreflectometers. The results from the precision study indicated that, at 95% confidence level, the retroreflectivity values from two properly conducted tests using a single handheld device on the same pavement marking should not differ by more than 3.0%, and when multiple handheld devices were used on the same pavement marking, the retroreflectivity values should not differ by more than 8.4%. A two-way ANOVA analysis indicates that neither marking line types nor retroreflectivity levels have significant influence on the repeatability and reproducibility of the handheld retroreflectometers. In addition, the handheld information was directly compared to field measurements collected from FDOT's mobile retroreflectivity unit (MRU), and the results indicated that the MRU demonstrated no statistical bias at a 95% confidence when compared with the handheld devices.

“Repeatability and Reproducibility of Mobile Retroreflectivity Units for Measurement of Pavement Markings,” Bouzid Choubane, Joshua Sevearance, Hyung Suk Lee, Patrick Upshaw and James Fletcher, *TRB 92nd Annual Meeting Compendium of Papers*, Paper #13-3812, 2013.

<http://docs.trb.org/prp/13-3812.pdf>

From the abstract:

The Florida Department of Transportation has historically used a combination of handheld devices and visual surveys to evaluate the retroreflectivity of pavement markings. However, visual surveys have the inherent limitations of operator bias, while the use of a handheld device is slow and labor intensive and presents safety hazards. Many highway agencies have recognized that a mobile retroreflectivity unit (MRU) may be a safer and more efficient alternative to the handheld retroreflectometers. Because the measurement process relies on the operator-driven instrument, a level of uncertainty is always a concern in evaluating pavement markings with the MRU. This research was aimed at assessing the precision and bias of the MRU while using the handheld retroreflectometer as a reference device. Ten 1.0-mi-long field sites were selected to include various pavement surface types and pavement marking materials (paints and thermoplastics). The results indicated that, when compared with the handheld retroreflectometers, the MRU demonstrated no statistical differences or bias at a 95% confidence level for the retroreflectivity values ranging between 200 and 800 mcd/m²/lux. In addition, it was determined that the retroreflectivity values from two properly conducted tests using a single MRU on the same pavement marking should not differ by more than 7.8%, and when different MRUs were used on the same pavement marking, the retroreflectivity values should not differ by more than 13.3%. This paper presents a description of the testing program, the data collection effort, and the subsequent analyses and findings.

“Characteristics of Calibration Standard for Mobile Retroreflectometer Unit,” James Fletcher, Joshua Sevearance, Bouzid Choubane and Charles R. Holzschuher III, *TRB 88th Annual Meeting Compendium of Papers DVD*, Paper #09-2103, 2009.

Citation at <https://trid.trb.org/view/2009/C/881558>

From the abstract:

In 2004, the Florida Department of Transportation (FDOT) acquired a Mobile Retroreflectometer Unit (MRU) to safely collect and process pavement marking retroreflectivity for a Pavement Marking Management System (PMMS). The goal of the program is the transition from site specific handheld retroreflectometers and subjective visual surveys to a continuous and high speed data collection methodology. MRU technology is still relatively new and previous studies have shown it is critical to understand

the operations of the device for valid test results. Crucial to the valid results is the calibration step, which is used to standardize the MRU response to a known retroreflectivity sample. Current calibration procedures typically require use of a short section of pavement line marking, often referred to as a beaded stripe, with a known retroreflectivity value as the MRU calibration standard. The beaded stripe has the advantage of being similar to the typical material measured by the MRU, but is inherently non-uniform due to a non-homogeneous pattern of glass bead placement and size. The non-uniformity of the glass beads creates the potential for issues with accuracy and repeatability of the calibration step. Ceramic blocks, which are used as the calibration standard for handheld retroreflectometers, have demonstrated a spatially uniform retroreflectivity response. This paper compares MRU calibration with the beaded stripe to that of a ceramic block, in part to show an alternative calibration standard. Initial testing has shown comparable calibration results when using a ceramic block versus the beaded line stripe. The study also attempts to validate the laboratory test results by conducting field experiments, comparing both the beaded calibration stripe and the ceramic block calibration methodologies.

Iowa

Development of a Presence Assessment Tool for Iowa's Pavement Marking Management System, Omar Smadi, Adnan El-Nasan and Neal Hawkins, Iowa DOT and Midwest Transportation Consortium, May 2011.

http://www.intrans.iastate.edu/reports/pvmt_markings_presence_tool_w_cvr.pdf

From the abstract:

Pavement marking quality is normally assessed using presence, or how much of the pavement marking material remains on the pavement, which provides daytime guidance, and retroreflectivity, or how visible the pavement marking material is at night. Both of these two measures determine pavement marking durability. This report discusses the use of image processing techniques to assess pavement marking quality. Images of pavement markings are processed using a number of operations. Image segmentation is the process of assigning the set of image pixels to regions having common characteristics. The proposed system tries to segment images of white or yellow pavement markings into foreground (marking) and background (pavement) parts. The images are then processed to determine pavement marking presence in an objective and consistent manner. The resulting assessment is critical to the implementation and development of a pavement marking management system and quality control/assurance processes.

Kentucky

Evaluation of Long-Term Pavement Marking Performance, Eric R. Green and Kenneth R. Agent, Kentucky Transportation Cabinet, December 2011.

http://www.ktc.uky.edu/files/2012/06/KTC_11_22_SPR_330_07_2I.pdf

From the abstract:

The objective of the investigation was to evaluate the useful life of pavement markings. The Manual on Uniform Traffic Control Devices (MUTCD) provides general guidelines for the application and installation of pavement markings. However, performance requirements for various types of pavement markings are not included. Retroreflectivity data were collected throughout Kentucky on various longitudinal pavement markings using mobile and manual techniques. Data were collected on one-year, two-year and three-year-old lines. The retroreflectivity levels were analyzed and several recommendations were made. Minimum levels of retroreflectivity should be set for determining what roads to restripe annually. These values should be lower than the passing/bonus thresholds used in the Quality

Control/Quality Assurance (QC/QA) program. It is recommended that yellow lines should be above 100 mcd/m²/lux and white lines should be above 150 mcd/m²/lux. Retroreflectivity measurements should be collected and used to determine which roads should be painted each year. The current Maintenance Rating Program (MRP) can be used to facilitate this process. An inventory of striped roads should be maintained to allow a determination of when specific roadway sections were last restriped.

Texas

“Quantitative Versus Qualitative Assessment of Pavement Marking Visibility,” Adam Pike, Shamanth Kuchangi and Robert Benz, *Transportation Research Record 2169*, pages 88-94, 2010.

Citation at <http://dx.doi.org/10.3141/2169-10>

From the abstract:

Many state departments of transportation (DOTs) often use a subjective evaluation program to assess the condition of their roadway assets. Because pavement markings are typically only a small part of these assessment programs and because visual assessment is subjective, the ratings may not always be accurate in identifying roadways with inadequate markings. This research sought to evaluate the accuracy of visual assessments of pavement markings. The Texas Transportation Institute conducted two separate nighttime evaluations as part of a Texas DOT research project. The first evaluation was conducted on open roads, and the second was conducted on a closed experimental course. Subjective rating data were collected on pavement markings by several DOT evaluators. To analyze the data, researchers compared retroreflectivity measurements with subjective ratings of the pavement markings. For the first night study, the average subjective rating of each marking compared with the measured retroreflectivity resulted in a logarithmic R² value of .818. The second night study resulted in a logarithmic R² value of .821 before training and .809 after training. The data were also evaluated by marking color and evaluator experience level. Researchers found that average subjective ratings showed acceptable correlation with retroreflectivity measurements, but ratings could show large variations between individuals. The researchers recommend that subjective assessment be considered a viable option for evaluating pavement markings. They also recommend that for any assessment the evaluator be well trained or multiple evaluators be utilized, with reported ratings averaged to provide reliable results.

Test Decks

“Predicting Pavement Marking Service Life with Transverse Test Deck Data,” Adam M. Pike and Praprut Songchitruksa, *Transportation Research Record 2482*, pages 16-22, 2015.

Citation at <http://dx.doi.org/10.3141/2482-03>

From the abstract:

Pavement marking test decks are an effective way to evaluate the quality of marking in the field. Transverse test decks provide accelerated wear on markings in the wheelpath area and can provide a side-by-side comparison of different pavement marking materials. The drawback is that the relationship between transverse and long-line pavement marking test decks is relatively unknown. This study was developed to provide better understanding of the relationship between the accelerated wear area on a transverse marking and how it relates to typical wear on a longitudinal marking. The objective of the study was to develop a model for predicting long-line pavement marking retroreflectivity values from transverse pavement marking test deck data. These models and associated parameters can be used to

estimate the retroreflectivity of an edge line marking or the amount of time it will take for the edge line marking to reach a given retroreflectivity level. The user needs only the transverse retroreflectivity readings and an initial or assumed initial edge line retroreflectivity value.

Development of Field Performance Evaluation Tools and Program for Pavement Marking Materials: Technical Report, Yunlong Zhang, Hancheng Ge, Adam Pike and Paul Carlson, Texas DOT, March 2011.

<http://tti.tamu.edu/documents/0-5548-1.pdf>

From the abstract:

Historically the prequalification or selection of pavement marking materials (PMMs) is mainly based on product specifications and lab testing, which do not correlate well with the field performance of the products. On the other hand, there is no consensus on recommended procedure to design a test deck and conduct a field performance test. The objective of this project is to investigate field evaluation plans and procedures and develop field performance-based evaluation procedures for PMMs. Field decks are designed incorporating regular long lines, long line in the travel lane, and transverse lines for accelerated testing, while also considering different installation procedures. Three different test field deck sites are selected across the state considering area climate, roadway surface type, and traffic condition. Carefully selected PMM products are installed and monitored for their field performance over time. The relationships between transverse and longitudinal test decks are evaluated with correlation analysis. Analysis results indicate that the points on transverse lines have high correlation with the corresponding five or seven longitudinal long lines in the travel lane when retroreflectivity values of all products on a test deck are averaged. For individual products, the correlations between transverse line locations and corresponding long lines in the travel lane exist, albeit at a lower level. A tracking database is developed and can record and interactively query all relevant data, track individual jobs and products, and graphically display performance changes over time.

Enhancements to Pavement Marking Testing Procedures, Ida van Schalkwyk, Oregon DOT and Federal Highway Administration, August 2010.

http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/2010/Pavement_Marking_Testing.pdf

From the abstract:

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

Appendix A: Survey Results

The full text of each survey response is provided below. For reference, we have included an abbreviated version of each question before the response. Where applicable, portions of the survey have been omitted if the respondent chose not to respond to a series of questions. Responses to the warranty survey begin below; responses to the retroreflectivity survey begin on page 11. The full question text appears on pages 8 and 15 of this Preliminary Investigation.

Warranty Survey Results

Alabama

Contact: Steven Ingram, Testing Engineer, Alabama DOT, ingrams@dot.state.al.us, 334-206-2335.

1. **Warranty type:**
 - Materials
2. **Extent of warranty program:** Statewide.
- 2A. **Criteria to determine warranty qualification:** [No response.]
- 2B. **Identify and track pavement segments:** [No response.]
3. **Performance criteria:**
 - Minimum retained retroreflectivity
 - Color retention
4. **Length of warranty period:** Six years longitudinal; two years legends and symbols.
5. **Pavement marking warranty specifications:**

Permanent Traffic Marking Materials and Producers, List V-4, Permanent Traffic Marking, Alabama DOT, February 2016.
<http://www.dot.state.al.us/mtweb/Testing/MSDSAR/doc/QMSD/Lv04.pdf>
See page 6 of this document for the warranty specifications for traffic marking materials.
6. **Certification/other process to determine project acceptance:** [No response.]
7. **Payment schedule:** [No response.]
8. **Project bonding required?** Yes.
- 8A. **When bond required to be issued:** Prior to construction beginning.
- 8B. **Determining bond value:** [No response.]
9. **Dispute resolution process?** Yes, normally by Construction Bureau.
10. **Program practices:**
 - Qualified products lists
11. **Costs differ for warranty versus nonwarranty markings?** [No response.]
12. **Budget allocation for monitoring markings:** [No response.]

13. **Additional resources needed to implement warranty program:** [No response.]
14. **Frequency of performance inspections:** [No response.]
15. **Who conducts inspections?** Agency staff.
16. **Tracking results of performance inspections:** [No response.]
17. **Types of corrective action:** [No response.]
18. **Include provisions for minimum retroreflectivity values?** Yes.
19. **Initial retroreflectivity value:** 130 mcd.
20. **When initial retroreflectivity value taken:** Immediately after installation.
21. **Required retained retroreflectivity value:** 130 mcd.
22. **Required value varies over time?** No.
23. **Measuring retained retroreflectivity:** 30-meter geometry.

Kansas

Contact: Jonny Madrid, Pavement Marking Specialist, Kansas DOT, jmadrid@ksdot.org, 785-296-7432.

1. **Warranty type:**
 - Materials and workmanship
2. **Extent of warranty program:** Statewide.
- 2A. **Criteria to determine warranty qualification:** All markings that are applied on the roadway are warranted by workmanship warranty by the contractor for 180 days. Also we require all manufacturers to warrant their material that has made it onto our PQL [Prequalified Materials Listing] to last a minimum of three years to a maximum of seven depending on the material.
- 2B. **Identify and track pavement segments:** All pavement markings that are applied onto any highway in Kansas will have a warranty tied to them.
3. **Performance criteria:**
 - Initial installation requirements (including initial minimum retroreflectivity)
 - Durability
 - Color retention
4. **Length of warranty period:** Workmanship warranty is 180 days. After that the manufacturer's warranty take[s] place, which ranges from three to seven years based on pavement marking material.
5. **Pavement marking warranty specifications:**

Section 806, Durable Pavement Marking, Standard Specifications, Kansas DOT, 2015.
<http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burConsMain/specprov/2015/806.pdf>
f
This specification addresses the agency's retroreflectivity requirements but does not

include warranty-related provisions.

6. **Certification/other process to determine project acceptance:** Retroreflectivity readings are taken 12 hours to 14 days after project is complete. At that point retro[reflectivity] values must be higher than what is stated as minimum i[n] our specification. Once that has been accepted, the start of the 180-day workmanship warranty starts.
7. **Payment schedule:** Cannot answer at this time.
8. **Project bonding required?** No.
- 8A. **When bond required to be issued:** [No response.]
- 8B. **Determining bond value:** [No response.]
9. **Dispute resolution process?** No.
10. **Program practices:**
 - Contractor-provided test sections
 - Materials manufacturer's training or other technical assistance
 - Prequalification of contractors
 - Qualified products lists
 - Required meetings during the warranty period that include all parties
11. **Costs differ for warranty versus nonwarranty markings?** All markings carry warranty.
12. **Budget allocation for monitoring markings:** N/A.
13. **Additional resources needed to implement warranty program:** [No response.]
14. **Frequency of performance inspections:** Anytime route is driven by agency staff members inspections are normally done at that time.
15. **Who conducts inspections?** Agency staff.
16. **Tracking results of performance inspections:** Visual inspections by driving route.
17. **Types of corrective action:** Based on amount of pavement marking failure, replacement of line is required and pay reduction may be given based on total amount of failures.
18. **Include provisions for minimum retroreflectivity values?** Yes.
19. **Initial retroreflectivity value:** Minimum values we set are:
 - Cold plastic: 250 white, 175 yellow.
 - Pattern cold plastic: 500 white, 300 yellow.
 - Epoxy/multicomponent: 325 white, 250 yellow.
 - High-durability tape: 225 white, 175 yellow.
 - Thermoplastic: 300 white, 225 yellow.
20. **When initial retroreflectivity value taken:** 12 hours to 14 days after project is complete.
21. **Required retained retroreflectivity value:** N/A.
22. **Required value varies over time?** No.
23. **Measuring retained retroreflectivity:** By taking retro[reflectivity] readings every mile. Five

reading[s] per line every mile.

24. **Process if failure to meet required values under warranty?** Replacement of markings, reduction of payment to contractor.
25. **Standard specification or special provision:**

Section 806, Durable Pavement Marking, Standard Specifications, Kansas DOT, 2015.
<http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burConsMain/specprov/2015/806.pdf>

This specification addresses the agency's retroreflectivity requirements but does not include warranty-related provisions.
26. **Successes in managing warranty program:** With holding both contractor and manufacturer accountable for pavement markings under said warranty, we have seen an increase in quality lines being installed.
27. **Challenges in managing warranty program:** Lack of contractor maintaining stripe trucks has created some pavement markings failures on projects, resulting in parts or all of project needing restriped.
28. **Comments or additional information:** [No response.]

Oregon (Response 1)

Contact: Joel Fry, Maintenance and Operations Branch/Field Operations Specialist, Oregon DOT, joel.d.fry@odot.state.or.us, 503-986-4485.

1. **Warranty type:**
 - Materials
2. **Extent of warranty program:** Our warranties are for durable pavement markings, high-performance pavement markings and legend markings.
- 2A. **Criteria to determine warranty qualification:** All of our construction project[s] have the pavement marking warranty requirements.
- 2B. **Identify and track pavement segments:** I maintain a spreadsheet tracking installation of pavement markings. This spreadsheet includes highway and milepoint range for each project, quantities, unit prices for the markings, and the completion date.
3. **Performance criteria:**
 - Minimum retained retroreflectivity
 - Durability
 - The construction specifications also include a minimum retroreflectivity level for acceptance.
4. **Length of warranty period:** For longline surface-applied thermoplastic, the warranty is three years. For longline inlaid thermoplastic, all methyl methacrylate applications and tape applications are four years. Longline high-performance markings are one year. Legends are 18 months.
5. **Pavement marking warranty specifications:**

Section 00850, Common Provisions for Pavement Markings, Part 00800, Permanent Traffic Safety and Guidance Devices, Oregon Standard Specifications for Construction, Oregon DOT, 2015.

http://www.oregon.gov/ODOT/HWY/SPECS/docs/15book/15_00800.pdf

Section 00850, which begins on page 22 of the publication (page 26 of the PDF), includes these subsections of particular interest:

- Specifications for longitudinal durable markings—see page 35 of the publication (page 39 of the PDF).
- Specifications for longitudinal high-performance markings—see page 37 of the publication (page 41 of the PDF).
- Specifications for transverse bars and legends—see page 40 of the publication (page 44 of the PDF).

6. **Certification/other process to determine project acceptance:** We have test method TM 777 [Test Method 777; see Related Resource below] that outlines the retroreflectivity testing frequency. Our acceptance level is at least 250 mcd/m²/lx for white markings and at least 200 mcd/m²/lx for yellow markings.

Related Resource:

ODOT TM 777: Method of Test for Evaluation of Retroreflectivity of Durable and High Performance Pavement Markings Using Portable Hand-Operated Instrument, Manual of Field Test Procedures, Oregon DOT, 2015.

ftp://ftp.odot.state.or.us/techserv/construction/TrainingManuals/MFTP/2015/03_ODOT_test_methods.pdf

Test Method 777, which begins on page 147 of the PDF, is used to test the dry retroreflectivity of durable and high-performance pavement markings using portable hand-operated instruments.

7. **Payment schedule:** When we receive all the required documentation from the contractor and the engineer accepts the work and authorizes final payment, the retainage is released to the contractor. The warranty is with the material manufacturer not the contractor.
8. **Project bonding required?** Yes.
- 8A. **When bond required to be issued:** At the beginning of the project.
- 8B. **Determining bond value:** The size or value of the project determines the level of bonding required.
9. **Dispute resolution process?** Yes. Our specification requires the material manufacturer will certify the contractors to be trained to install the material properly. The material manufacturer has a technical representative on site during installation to insure proper application.
10. **Program practices:**
- Materials manufacturer's training or other technical assistance
11. **Costs differ for warranty versus nonwarranty markings?** All of our construction project[s] require the warranty so we have no way to tell if there would be a difference.
12. **Budget allocation for monitoring markings:** There is no budget specific to monitoring; it is just another duty we perform.

13. **Additional resources needed to implement warranty program:** The material manufacturer agrees to warranty program to get their material approved. We purchased a handheld retroreflectometer for each of the pavement marking crews and one for my office to check materials still under warranty.
14. **Frequency of performance inspections:** If the performance of markings is questioned we will go and evaluate to determine the performance level, but we have no regularly scheduled testing.
15. **Who conducts inspections?** Agency staff.
16. **Tracking results of performance inspections:** I have a list of projects that imposed the warranty and track the timelines of acceptance, notification and repair. I also keep the information for projects tested but not requiring warranty repair.
17. **Types of corrective action:** When notified of warranty issue the time clock stops until the repairs are accepted. If the repairs [are] not completed, the manufacturer's material is removed from our qualified products list.
18. **Include provisions for minimum retroreflectivity values?** Yes.
19. **Initial retroreflectivity value:** We have retroreflectivity levels for project acceptance. Our warranty states the retroreflectivity must maintain at least 150 mcd/m²/lx for white and 125 for yellow throughout the warranty period.
20. **When initial retroreflectivity value taken:** Within two days of application, but this is for project acceptance.
21. **Required retained retroreflectivity value:** 150 mcd/m²/lx for white and 125 for yellow. The legend requirement is 100 mcd/m²/lx.
22. **Required value varies over time?** No.
23. **Measuring retained retroreflectivity:** Delta LTL-X handheld retroreflectometer [see <http://roadsensors.madebydelta.com/products/ltl-x/> for product details.]
24. **Process if failure to meet required values under warranty?** The warranty is with the manufacturer.
25. **Standard specification or special provision:**

Section 00170.85(c)(1), Responsibility for Defective Work, Part 00100, General Conditions, Oregon Standard Specifications for Construction, Oregon DOT, 2015. http://www.oregon.gov/ODOT/HWY/SPECS/docs/15book/15_00100.pdf#page=84 Page 80 of the publication (page 84 of the PDF) addresses general requirements for manufacturer warranties and guarantees.
26. **Successes in managing warranty program:** Less than 5 percent of our construction projects have had a warranty issue. We have activated 110 warranties and only five were not resolved.
27. **Challenges in managing warranty program:** The warranty is with the material manufacturer so we have no leverage to get the contractor to repair the markings.
28. **Comments or additional information:** [No response.]

Oregon (Response 2)

Contact: Eric Leaming, Traffic Devices Engineer, Traffic-Roadway Section, Oregon DOT, eric.s.leaning@odot.state.or.us, 503-986-3610.

1. **Warranty type:**
 - Materials
2. **Extent of warranty program:** Project-based.
- 2A. **Criteria to determine warranty qualification:** Any new construction not using waterborne paint is warranted by the manufacturer for a certain time period. More durable materials (thermoplastics and MMA [methyl methacrylate]) are warranted longer than less durable (hi-build paint, epoxies).
- 2B. **Identify and track pavement segments:** After markings are installed, the manufacturer supplies ODOT with a standard form with the project location (milepoint-milepoint), date installed, material and duration of warranty. After the project is closed, the local striping maintenance manager is the holder of the warranty. We have a statewide coordinator for warranties that acts as the point of contact for manufacturers and maintenance managers.
3. **Performance criteria:**
 - Minimum retained retroreflectivity
 - Durability
 - Color retention
4. **Length of warranty period:** Beginning at the project's Second Note (end of contract time):
 - Longitudinal Thermoplastic, Surface Applied: 3 years.
 - Longitudinal Thermoplastic, Groove Applied: 4 Years.
 - Longitudinal MMA, Surface & Groove Applied: 4 Years.
 - Longitudinal Tape: 4 Years.
 - Modified Urethanes (Surface & Groove Applied): 1 Year.
 - Hi-Build Paint (Surface & Groove Applied): 1 Year.
 - Polyureas (Surface & Groove Applied): 1 Year.
 - All transverse bars and legends: 1.5 Years.
5. **Pavement marking warranty specifications:**

Section 00850, Common Provisions for Pavement Markings, Part 00800, Permanent Traffic Safety and Guidance Devices, Oregon Standard Specifications for Construction, Oregon DOT, 2015.
http://www.oregon.gov/ODOT/HWY/SPECS/docs/15book/15_00800.pdf
Section 00850, which begins on page 22 of the publication (page 26 of the PDF), includes these subsections of particular interest:

 - Specifications for longitudinal durable markings—see page 35 of the publication (page 39 of the PDF).
 - Specifications for longitudinal high-performance markings—see page 37 of the publication (page 41 of the PDF).

- Specifications for transverse bars and legends—see page 40 of the publication (page 44 of the PDF).
6. **Certification/other process to determine project acceptance:** The contractor must be certified by the material manufacturer and a manufacturer's representative must be on-site during installation to ensure conditions are right for their material (that they're warranting) to go down. An agency inspector ensures markings are placed in the proper location within tolerances. The contractor also must measure retroreflectivity every 300 feet to determine if the new line meets minimum standards.
 7. **Payment schedule:** Markings are paid in full at the end of the installation project. The way our warranty program is structured does not lend itself to prompt response from contractors. Our warranty is with the manufacturer, so our guarantee the manufacturer will follow through is limited to removing their failing product from our qualified list. In some cases, we've completely removed a company's full product portfolio from our qualified list for multiple failures with delinquent repairs.
 8. **Project bonding required?** No.
 - 8A. **When bond required to be issued:** [No response.]
 - 8B. **Determining bond value:** [No response.]
 9. **Dispute resolution process?** Yes. 1) Agency notifies the manufacturer of the product failure. Warranty period time clock stops. Manufacturer has six months to repair product failure. 2) Manufacturer contacts a contractor to make repair. 3) If repair is made in accordance with specifications, warranty clock resumes. 4) If repair is not made, agency submits letter to manufacturer requiring a detailed plan to resolve issue within certain time frame. If manufacturer does not resolve the issue, the failed product is removed from agency's Qualified Product List.
 10. **Program practices:**
 - Contractor-provided test sections
 - Materials manufacturer's training or other technical assistance
 - Prequalification of contractors
 - Qualified products lists
 - Work plans or other documents required for submission by the contractor during the warranty period
 11. **Costs differ for warranty versus nonwarranty markings?** We have not formally studied the cost impacts of our warranty program, but we suspect costs are increased to the agency so the manufacturer can manage risk.
 12. **Budget allocation for monitoring markings:** [No response.]
 13. **Additional resources needed to implement warranty program:** Statewide coordinator.

Virginia

Contact: Harry A. Campbell, Traffic Engineering Division, Virginia DOT,
harry.campbell@vdot.virginia.gov, 804-786-6374.

1. **Warranty type:**
 - Materials and workmanship
2. **Extent of warranty program:** Only covers when B-VI reflective tape is specified. Warranty is six years with specific provisions.
- 2A. **Criteria to determine warranty qualification:** B-VI reflective tape is specified for interstate and other limited-access facilities where pavement life is expected to last six years or more [see citation below].

Type B, Class VI Pavement Markings, Traffic Engineering Division Memorandum, Virginia DOT, September 2011.

http://www.virginiadot.org/business/resources/traffic_engineering/memos/261.1_TypeB_ClassVI_Pavement_Markings.pdf.

From the memorandum:

The Department is revising its policy on the use of Type B, Class VI pavement markings to increase flexibility and reduce constructability concerns. This memorandum outlines areas where Type B, Class VI markings shall be used and areas where they may be used subject to engineering judgment. This clarification is effective for projects to be issued for advertisement on or after December 1, 2014.

- 2B. **Identify and track pavement segments:** Regional maintenance works with the districts by tracking project records.
3. **Performance criteria:** Both manufacturers of B-VI provide a detailed specific warranty. Their warranty covers the contractors' installation.
4. **Length of warranty period:** Six years.
5. **Pavement marking warranty specifications:** Manufacturer warranty is separate, is part of the preapproved products process and on file at Materials Division. Will see if I can get you a copy. Most recent paving schedule specification:

Special Provision for Type B, Class VI Pavement Line Marking Tape, Plant Mix Schedules (Volume 2 of 2), Special Provision Copied Notes, Special Provisions and Supplemental Specifications for Plant Mix Schedules—Statewide, Virginia DOT, July 2015.

http://www.virginiadot.org/business/resources/const/Announce_VOL2_2016_F_PlantMix.pdf

This special provision, which begins on page 279 of the publication (page 283 of the PDF), addresses initial approval, retroreflectivity requirements, installation, post-installation evaluation, requirements under the warranty, measurement and payment.

Other provisions not subject to warranty but addressing retroreflectivity appear on page 260 (page 264 of the PDF) and page 283 of the publication (page 287 of the PDF).

6. **Certification/other process to determine project acceptance:** [See the citation above.]
7. **Payment schedule:** None.
8. **Project bonding required?** Yes.

- 8A. **When bond required to be issued:** The entire project has a bond and markings [are] just part of that. The warranty covers the B-VI.
- 8B. **Determining bond value:** I believe Division 100 describes the requirements [see below]:
- Section 103, Award and Execution of Contracts**, Road and Bridge Specifications, Virginia DOT, 2016.
http://www.virginiadot.org/business/resources/const/Specs_CombinedBook.pdf
See page 25 of the document for Section 103, which addresses bonds.
9. **Dispute resolution process?** Yes. I believe Division 100 covers that [see above citation].
10. **Program practices:**
- Qualified products lists
 - The B-VI Tape manufacturer underwrites the warranty.
11. **Costs differ for warranty versus nonwarranty markings?** A six-inch line in B-VI is around \$3.50 per foot versus about a dollar or more a foot for thermoplastic.
12. **Budget allocation for monitoring markings:** No designated budget.
13. **Additional resources needed to implement warranty program:** None to my knowledge.
14. **Frequency of performance inspections:** Other than the interstate maintenance contractor and VDOT staff driving the interstate, there is no specific performance inspection.
15. **Who conducts inspections?** Other than the interstate maintenance contractor and VDOT staff driving the interstate, there is no specific performance inspection.
16. **Tracking results of performance inspections:** Other than the interstate maintenance contractor and VDOT staff driving the interstate, there is no specific performance inspection. Observed problems are reported.
17. **Types of corrective action:** Manufacturer will bring in the contractor or hire another contractor to correct if there is a warranty failure.
18. **Include provisions for minimum retroreflectivity values?** No.
26. **Successes in managing warranty program:** Inlaid B-VI performs better than any other durable markings. Performance is typically about six years when inlaid properly.
27. **Challenges in managing warranty program:** If not inlaid properly, the tape will come up with the first snowplow operation. Surface application on latex emulsion surfaces have been a challenge. See the paving schedule specifications. Snowplow operations do degrade the retro[reflectivity] value.
28. **Comments or additional information:** Please provide us with the survey results:
harry.campbell@vdot.virginia.gov.

Retroreflectivity Survey Results

Delaware

Contact: Nick Mogle, Traffic Division, Delaware DOT, nick.mogle@state.de.us, 302-760-2589.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** All new construction is subject to meeting minimum retroreflectivity values.
- 1B. **Identify and track pavement segments:** Contractor is responsible to submit locations for testing one striping completed.
2. **Initial retroreflectivity value:** 450 white; 375 yellow.
3. **Minimum value for a specified time period?** No.
- 3A. **Required value varies over time?** [No response.]
4. **Standard specification or special provision:** [No response.]
5. **When initial retroreflectivity value taken:** Within 30 days.
6. **Measuring retained retroreflectivity:** N/A.
7. **Frequency of performance inspections:** [No response.]
8. **Who conducts inspections?** Agency staff.
9. **Tracking results of performance inspections:** Spreadsheet.
10. **Process if failure to meet minimum requirements:** Contractor is contacted and told material failed to meet specification/standards and must be replaced.
11. **Successes in applying retroreflectivity values:** We have ended up seeing more consistency with the quality of line.
12. **Challenges in applying retroreflectivity values:** One of the main challenges is when markings are applied in the fall of the year sometimes they get snowplowed before they can be given a fair evaluation.
13. **Comments or additional information:** [No response.]

Georgia

Contact: Richard Douds, Testing Bureau Chief, Office of Materials and Testing, Georgia DOT, rdouds@dot.ga.gov, 404-694-6676.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** Our standard specifications have retroreflectivity performance criteria for all approved pavement markings.
- 1B. **Identify and track pavement segments:** Contractors are required to obtain retroreflective readings within the first 30 days and again at 180 days for acceptance. The readings must meet or exceed required performance retroreflectivity numbers. Both sets of readings become part of the project files.
2. **Initial retroreflectivity value:** Depends on the pavement marking material and the ADT

[average daily traffic] of the roadway; 8,000 or less ADT we use high-build paint. The values are less than the requirements for our interstates. Preformed tape and polyurea longitudinal striping must meet 600 mcd/lux/m² white and 400 mcd/lux/m² yellow. We also have wet reflective requirements.

3. **Minimum value for a specified time period?** Yes. For 180 days not go below required performance values in specifications for specific pavement marking materials. Only preformed plastic tape has a manufacturer's warranty.
- 3A. **Required value varies over time?** No.
4. **Standard specification or special provision:** Will forward.
5. **When initial retroreflectivity value taken:** Within 30 days after installation.
6. **Measuring retained retroreflectivity:** With a handheld retroreflectometer.
7. **Frequency of performance inspections:** Randomly within the first 30 days or within the first six months.
8. **Who conducts inspections?** Agency staff.
9. **Tracking results of performance inspections:** If the material fails to meet requirements then corrective work is required.
10. **Process if failure to meet minimum requirements:** The contractor is required to correct the work at no additional cost to the department.
11. **Successes in applying retroreflectivity values:** We met with contractors and manufacturers and set up numerous test decks to establish numbers that are achievable but still maintain a high performance standard.
12. **Challenges in applying retroreflectivity values:** The wet reflective values are mainly achieved by one product.
13. **Comments or additional information:** We require initial and 180-day retroreflectivity readings that meet or exceed our performance requirements for acceptance to ensure the pavement markings will perform as required. We only have a warranty in our specifications for preformed plastic tape. It is guaranteed not to go below 100 mcd/lux/m² for six years. The manufacturer will replace the pavement marking material if it fails to meet the requirement in our specifications [see the excerpt below provided by the respondent.]

657.3.07 Contractor Warranty and Maintenance

A. Warranties

Transfer all warranties or guarantees normally furnished by the manufacturer to the Department. Include a provision that warranties are subject to transfer. Warrant Type PB Plastic Markings to adhere to the pavement and to provide a minimum coefficient of retroreflection of 100 mcd/lux/m² when measured using a 30 meter geometry retroreflectometer for a period of at least 6 years for longitudinal markings and at least 2 years for intersection markings and symbols under normal traffic conditions.

Iowa

Contact: Tim Crouch, Office of Traffic and Safety, Iowa DOT, tim.crouch@dot.iowa.gov, 515-239-1513.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** [No response.]
- 1B. **Identify and track pavement segments:** [No response.]
2. **Initial retroreflectivity value:** It depends on the type of material specified.
3. **Minimum value for a specified time period?** No.
- 3A. **Required value varies over time?** [No response.]
4. **Standard specification or special provision:**

Section 2527, Pavement Marking, Standard Specifications, Iowa DOT, 2015.

<http://www.iowadot.gov/erl/current/GS/content/2527.htm>

This specification describes the materials and construction requirements associated with the agency's pavement marking installations.

Section 4183, Traffic Paints and Pavement Markings, Standard Specifications, Iowa DOT, 2015.

<http://www.iowadot.gov/erl/current/GS/content/4183.htm>

This specification provides formulation guides for paint, field service requirements, and testing and acceptance for pavement marking tape and two types of fast-dry traffic paint—volatile organic compound-compliant solvent borne paint and waterborne paint.

5. **When initial retroreflectivity value taken:** Between seven and 35 days after installation.
6. **Measuring retained retroreflectivity:**
 - Determining Retroreflectivity of Durable Pavement Markings**, Instructional Memorandum 386, Iowa DOT, undated.
<http://www.iowadot.gov/erl/current/IM/content/386.htm>
This document describes the testing required for final acceptance of pavement marking installations and includes sample forms.
7. **Frequency of performance inspections:** Performance inspections are not conducted.
8. **Who conducts inspections?** N/A.
9. **Tracking results of performance inspections:** N/A.
10. **Process if failure to meet minimum requirements:** Markings that are low on initial retroreflectivity up to 20 percent may, at the discretion of the Engineer, be accepted with a price adjustment. Repair, at no additional cost to the Contracting Authority, all pavement markings which, after application and curing, the Engineer determines to be defective and not in conformance with these specifications. Remove the defective markings completely and clean to the underlying pavement surface according to the requirements of Article 2527.03, C. Remove the defective area plus all adjacent marking material extending 1 foot (300 mm) in any direction. After surface preparation work is complete, finish the repair by reapplying new marking material over the cleaned pavement surface according to the requirements of these specifications.
11. **Successes in applying retroreflectivity values:** Quality of the pavement markings has

improved, as well as durability.

12. **Challenges in applying retroreflectivity values:** Getting all the readings taken.
13. **Comments or additional information:** [No response.]

Kentucky

Contact: Jeff Wolfe, Traffic Operations, Kentucky Transportation Cabinet, jeff.wolfe@ky.gov, 502-782-5546.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** Retro[reflectivity] is measured initially on all striping due to our performance specification. Retro[reflectivity] is evaluated statewide through our maintenance rating program.
- 1B. **Identify and track pavement segments:** Generate a relevant sample size for measuring various maintenance items, including striping retro[reflectivity], through our maintenance rating program.
2. **Initial retroreflectivity value:** Initial proving period (30 to 60 days after application).
 - White: 300 mcd/lux/square meter.
 - Yellow: 225 mcd/lux/square meter.
3. **Minimum value for a specified time period?** No.
- 3A. **Required value varies over time?** No.
4. **Standard specification or special provision:**

Section 713, Permanent Pavement Striping, Standard Specifications for Road and Bridge Construction (June 2014 Supplemental Specifications Included), Kentucky Transportation Cabinet, 2012/2014.

<http://transportation.ky.gov/Construction/StdSpecsWSupplSpecs/2012%20Standard%20Spec%20with%20Supp%20Spec%20June%202014.pdf>

Section 713 begins on page 415 of the PDF and includes the agency's retroreflectivity requirements.

Michigan

Contact: Mary K. Bramble, Pavement Marking and Delineation Engineer, Traffic and Safety Section, Design Division, Michigan DOT, bramble1@michigan.gov, 517-335-2837.

In lieu of completing the survey, the Michigan DOT respondent provided these comments:

I took a look at the surveys, but have not completed one since neither really applies to Michigan's practices. We do not use pavement marking warranties, nor do we apply retro[reflectivity] minimums to field applications of established materials.

When product applications are submitted for our Qualified Products List, we check retroreflectivity both in the NTPEP [National Transportation Product Evaluation Program] data and then at a field test application, evaluating initial and worn retroreflectivity values. We do also take annual retroreflectivity readings in the spring on much of our system, but the readings are for information only. Much of this is related to the fact that, via contracting,

Michigan restripes approximately 85-90 percent of our roadway system each year with nondurable materials (waterborne and sprayable thermoplastic). Use of durable materials is limited to some construction projects, and at the end of its service life (approximately three to five years), the durable product will be covered over in the annual projects and then continue [to] be striped over each year.

Minnesota

Contact: Michelle Moser, Pavement Marking and Traffic Device Engineer, Minnesota DOT, michelle.moser@state.mn.us, 651-234-7380.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** [No response.]
- 1B. **Identify and track pavement segments:** [No response.]
2. **Initial retroreflectivity value:**
 - Preformed Tape:*
 - White: 600 mcd/sq. m/lux
 - Yellow: 500 mcd/sq. m/lux
 - Preformed Thermoplastic:*
 - White: 400 mcd/sq. m/lux
 - Yellow: 250 mcd/sq. m/lux
 - Preformed Thermo (Enhanced Skid Resistance):*
 - White: 250 mcd/sq. m/lux
 - Yellow: 150 mcd/sq. m/lux
 - Epoxy:*
 - White: 300 mcd/sq. m/lux
 - Yellow: 200 mcd/sq. m/lux
 - Paint:*
 - White: 275 mcd/sq. m/lux
 - Yellow: 180 mcd/sq. m/lux
3. **Minimum value for a specified time period?** No.
- 3A. **Required value varies over time?** [No response.]
4. **Standard specification or special provision:**

Section 2582, Pavement Markings, Standard Specifications for Construction, Minnesota DOT, 2016.
<http://www.dot.state.mn.us/pre-letting/spec/2016/2016specbook.pdf>
Section 2582 begins on page 530 of the PDF and includes the agency's retroreflectivity requirements.
5. **When initial retroreflectivity value taken:** Fourteen to 45 days.
6. **Measuring retained retroreflectivity:** Districts can submit requests to have sections of markings measured that they think may be reaching our minimum retroreflectivity for replacement, which is 80 mcd for yellow and 100 mcd for white.

7. **Frequency of performance inspections:** District maintenance staff regularly drive and assess markings both day and night. Actual retroreflectivity measurements are done at their request.
8. **Who conducts inspections?** Agency staff.
9. **Tracking results of performance inspections:** Districts keep track of their pavement marking quality and replacement plans.
10. **Process if failure to meet minimum requirements:** If a new pavement marking fails to meet initial retro[reflectivity] requirements, the contractor is either subject to a deduction, if the marking fails by less than 20 percent, or has to replace the marking if it is failing by more than 20 percent. In terms of maintenance, once a marking is nearing the minimum values of 80 yellow or 100 white, the district will schedule it for refreshing. We have our own pavement marking crews that work full time during the construction season refreshing markings across the state.
11. **Successes in applying retroreflectivity values:** We have seen pavement marking quality increase, as contractors have responded with increased compliance to our mobile retroreflectometer measurement program.
12. **Challenges in applying retroreflectivity values:** Some contractors contend that our values are too high to reach, especially on rumble strips. We struggle with marking pavement preservation projects with surfaces like seal coats or fog sealed surfaces.
13. **Comments or additional information:** [No response.]

Missouri

Contact: Tom Honich, Traffic and Highway Safety, Missouri DOT, thomas.honich@modot.mo.gov, 573-526-0122.

1. **Use of minimum retroreflectivity values:** Statewide.
 - 1A. **Criteria to determine performance monitoring:** Minimum retro[reflectivity] values are used as the performance benchmark from [which] the contractor gets paid. Currently if they exceed 300 for white and 225 for yellow they get full payment. If they fall below those numbers on a new stripe there are provisions for them to restripe or take a deduct[ion]; if it falls below a certain level, a restripe is required. We are considering increasing these minimums next year. Last year we changed our marking system to an ASTM Type III bead on our major routes for improved retro[reflectivity] and wet nighttime performance. Based on readings taken this year, our contractors can easily achieve 400 and 325 on a new surface, and as high as 700 on white. Our maintenance crews will still likely use the 300 - 225 as surface conditions have a significant impact on achievable retro[reflectivity] values.
 - 1B. **Identify and track pavement segments:** We are predominately a waterborne paint system state at this time. Once a line is applied by a contractor, measured and paid, that ends the retro[reflectivity] measurements. Pavement marking maintenance is performed on all routes by MoDOT crews and trucks. They use nighttime visual and/or handheld readings to judge the performance of a line and if it can be skipped for another year. We utilize 200 for white and 175 for yellow as minimum levels we expect will make it through another winter, with 150 and 125 being the failure points for white and yellow, respectively. These numbers were determined via an internal research study conducted many years ago.
2. **Initial retroreflectivity value:** 300 white / 225 yellow for contractors and maintenance

forces alike. Contractor expectations are likely to be increased based on pavement marking material changes we recently made.

3. **Minimum value for a specified time period?** To some degree, we have minimum levels for a new line, then minimum levels a line would need to meet to be skipped for another year and failure levels.
- 3A. **Required value varies over time?** No.
4. **Standard specification or special provision:**
 - Category: 620.12 Construction Inspection for Sec 620**, Engineering Policy Guide, Missouri DOT, February 2015.
http://epg.modot.org/index.php?title=620.12_Construction_Inspection_for_Sec_620
This specification provides the agency's construction requirements for various types of pavement markings.
 - Category: 620.13 Measurement of Retroreflectivity by Handheld Retroreflectometers**, Engineering Policy Guide, Missouri DOT, February 2015.
http://epg.modot.org/index.php?title=620.13_Measurement_of_Retroreflectivity_by_Handheld_Retroreflectometers
These guidelines "are based on MoDOT Test Method T80 and ASTM D7585-10. These guidelines are to be used by MoDOT forces when determining the quality and remaining life of MoDOT pavement markings, both existing and newly applied."
[See http://epg.modot.org/files/d/db/620.10_MoDOT_T80.pdf for Test Method T80, Measurement of Retroreflectivity by Handheld Retroreflectometers; see <http://www.astm.org/Standards/D7585.htm> for ASTM D7585 / D7585M-10(2015), Standard Practice for Evaluating Retroreflective Pavement Markings Using Portable Hand-Operated Instruments.]
5. **When initial retroreflectivity value taken:** Within seven to 14 days typically; no longer than 45 days after application.
6. **Measuring retained retroreflectivity:** This is more of a maintenance operation conducted by our own crews to determine their yearly striping program and what segments may be skipped. It is based on handheld readings and nighttime visual inspections looking at the distance down the road a line can be seen.
7. **Frequency of performance inspections:** For contractors, just after installation as the measurement for payment; for maintenance, once a year during their planning for the season.
8. **Who conducts inspections?** We have a third-party contractor who performs the mobile retro[reflectivity] readings for contract-installed pavement markings and they also do random QA [quality assurance] readings to help us evaluate the state of our system overall.
9. **Tracking results of performance inspections:** Our inspections for the acceptance of our contract stripe works well. The major flaw is it is possible for the line to be covered (by dirt or debris) or damaged (by the contractor, for example, pulling up shoulders with a motor grader) where the line was applied correctly, but at the time of the readings it needs to be cleaned or it has been damaged and the prime contractor is held accountable. This is typically not under the striping contractor's control, but many times they pay the price.
10. **Process if failure to meet minimum requirements:** If the line falls below the minimums there is a percent deduct[ion] for each level below, or the contractor may choose to fix the deficient sections for full payment. There is also a minimum threshold below which

replacement is required.

11. **Successes in applying retroreflectivity values:** We believe good success; however, we have had cases with poor contractors where they apply a line that is good enough to give suitable initial values but will not last a year.
12. **Challenges in applying retroreflectivity values:** Since acceptance is primarily based on retro[reflectivity] values, thin paint holding just enough beads to meet [an] initial reading can get them full payment. We are working on ways to make this difficult to do by raising the bar on minimums and training inspectors on what to look for.
13. **Comments or additional information:** We use[d] to use a double drop wet element on our lane lines to achieve wet nighttime performance, but there was no efficient way to check wet nighttime performance and we had no spec other than application rate to measure against. With our move to ASTM Type III beads, we have found if we have good dry readings we have a high confidence level the wet nighttime performance is there because the beads are there.

Nebraska

Contact: Kevin Wray, Traffic/Signing and Marking Engineer, Nebraska Department of Roads, kevin.wray@nebraska.gov, 402-479-4594.

1. **Use of minimum retroreflectivity values:** Statewide pavement marking projects using thermo[plastic] or polyurea. State forces use waterborne paint to stripe state highways 1-2 times/year.
- 1A. **Criteria to determine performance monitoring:** [No response.]
- 1B. **Identify and track pavement segments:** [No response.]
2. **Initial retroreflectivity value:**
 - Polyurea: Dry white: 500; yellow: 350
 - Thermoplastic: Dry white: 400; yellow: 325
3. **Minimum value for a specified time period?** Have 180-day observation period for final acceptance.
- 3A. **Required value varies over time?** [No response.]
4. **Standard specification or special provision:**
 - D-15-1013, Wet Reflective Thermoplastic Pavement Marking, Grooved, Special Provisions, Nebraska Department of Roads, May 2011.**
See [Appendix B](#).
This special provision addresses application and retroreflectivity requirements, the observation period, and the basis for payment for retroreflective thermoplastic pavement markings.
 - D-17-1013, Wet Reflective Polyurea Pavement Marking, Grooved, Special Provisions, Nebraska Department of Roads, January 2013.**
See [Appendix C](#).
This special provision addresses application and retroreflectivity requirements, the observation period, and the basis for payment for retroreflective polyurea pavement

markings.

5. **When initial retroreflectivity value taken:** Two to 30 days after application.
6. **Measuring retained retroreflectivity:** 30-meter reflectometer.
7. **Frequency of performance inspections:** Annually.
8. **Who conducts inspections?** Agency staff.
9. **Tracking results of performance inspections:** Spreadsheet.
10. **Process if failure to meet minimum requirements:** The department may have the contractor remove and replace the pavement marking.
11. **Successes in applying retroreflectivity values:** [No response.]
12. **Challenges in applying retroreflectivity values:** Amount of markings to track.
13. **Comments or additional information:** [No response.]

New Hampshire

Contact: William Lambert, Operations/State Traffic Engineer, New Hampshire DOT, wlambert@dot.state.nh.us, 603-271-1679.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** [No response.]
- 1B. **Identify and track pavement segments:** [No response.]
2. **Initial retroreflectivity value:** 200 millicandelas for white and 150 for yellow markings.
3. **Minimum value for a specified time period?** No.
- 3A. **Required value varies over time?** [No response.]
4. **Standard specification or special provision:**

Section 632, Retroreflective Pavement Markings, Standard Specifications, New Hampshire DOT, 2016.
<http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2016NHDOTSpecBookWeb.pdf>
Section 632 begins on page 400 of the PDF and provides the agency's guidance on the use of retroreflective markings.
5. **When initial retroreflectivity value taken:** Within 30 days.
6. **Measuring retained retroreflectivity:** [No response.]
7. **Frequency of performance inspections:** N/A.
8. **Who conducts inspections?** Agency staff.
9. **Tracking results of performance inspections:** [No response.]
10. **Process if failure to meet minimum requirements:** Contractor must reapply markings in order to receive payment.
11. **Successes in applying retroreflectivity values:** Contractors seem to be more responsible when they know they need to meet minimum values in order to get paid. They don't want to

do it twice.

12. **Challenges in applying retroreflectivity values:** Getting contractors to accept failed results.
13. **Comments or additional information:** [No response.]

New York

Contact: Patrick Galarza, Civil Engineer 2, New York State DOT, patrick.galarza@dot.ny.gov, 518-457-4599.

1. **Use of minimum retroreflectivity values:** NYSDOT does not officially require any minimum retroreflectivity values.
- 1A. **Criteria to determine performance monitoring:** N/A.
- 1B. **Identify and track pavement segments:** Monitoring is done for product approval only.
2. **Initial retroreflectivity value:** N/A.
3. **Minimum value for a specified time period?** No.
- 3A. **Required value varies over time?** No.
4. **Standard specification or special provision:** NYSDOT does not have any required retroreflectivity values.
5. **When initial retroreflectivity value taken:** Not taken on normal projects.
6. **Measuring retained retroreflectivity:** Not measured on normal projects.
7. **Frequency of performance inspections:** Visual inspection at end of project.
8. **Who conducts inspections?** Agency staff with contractor assistance.
9. **Tracking results of performance inspections:** Not tracked.
10. **Process if failure to meet minimum requirements:** Any issues noted in newly applied markings is reported to Main Office. Main Office personnel will then investigate the installation.
11. **Successes in applying retroreflectivity values:** N/A.
12. **Challenges in applying retroreflectivity values:** N/A.
13. **Comments or additional information:** NYSDOT has no required retroreflectivity requirements.

North Carolina

Contact: Chris Howard, Signing and Delineation Engineer, North Carolina DOT, cbhoward@ncdot.gov, 919-661-3262.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** All projects.
- 1B. **Identify and track pavement segments:** We take an audit by contracting out a mobile retro[reflectometer]. We audit a percentage of the roadways that statistically gives us a 95

percent confidence rating.

2. **Initial retroreflectivity value:**

Thermoplastic: w[hite] 375 y[ellow] 250

Thermoplastic with highly reflective elements (HRE): w[hite] 700 y[ellow] 700

Polyurea: w[hite] 700 y[ellow] 700 (used to be w[hite] 800 y[ellow] 500 for HRE)

3. **Minimum value for a specified time period?** We are recommending a minimum value of 100. We have studies to know the life cycle of our markings.

3A. **Required value varies over time?** Don't understand this question, but basically when the markings get close to 100 or falls below it should be replaced.

4. **Standard specification or special provision:**

Division 12, Pavement Markings, Markers and Delineation, Standard Specifications for Roads and Structures, North Carolina DOT, January 2012.

<https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Roadway%20Standard%20Specifications%20Division%2012%20-%20Pavement%20Markings.%20Markers%20and%20Delineation.pdf>

This is the agency's specification related to pavement markings.

Thermoplastic Pavement Marking Material, (HRE), Project Special Provision, North Carolina DOT, January 2016.

[https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Thermoplastic Pavement Marking Material \(HRE\) Website.pdf](https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Thermoplastic%20Pavement%20Marking%20Material%20(HRE)%20Website.pdf)

This special provision describes the minimum retroreflectivity values, measurement and payment for the agency's thermoplastic pavement marking material.

Signing and Delineation, North Carolina DOT, undated.

<https://connect.ncdot.gov/resources/safety/Pages/Signing-and-Delineation.aspx>

This web page provides information and resources applicable to pavement marking, including specifications, special provisions and layouts.

"Pavement Marking Life Cycle Cost Analysis," Chris Howard, Matt Springer and Yusuf Sharif, North Carolina DOT, April 2015.

[https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Pavement Marking Cost Analysis.pdf](https://connect.ncdot.gov/resources/safety/Signing%20and%20Delineation%20Library/Pavement%20Marking%20Life%20Cycle%20Cost%20Analysis.pdf)

This presentation describes research conducted by the agency that produced a recommendation for immediate action to "[u]se long-life final markings on all TIP and Resurfacing projects, and in all cases where it is cost effective." The long-term recommendation is to use long-life markings on all final applications. The presentation also estimates that results of the agency's proposed changes in managing pavement markings will save an estimated \$15.8 million a year statewide.

5. **When initial retroreflectivity value taken:** Within 30 days.

6. **Measuring retained retroreflectivity:** Using a 30-meter retroreflectometer.

7. **Frequency of performance inspections:** We take an audit of our system. See life cycle presentation link.

8. **Who conducts inspections?** Agency staff with contractor assistance.

9. **Tracking results of performance inspections:** Centrally.
10. **Process if failure to meet minimum requirements:** Either a pay deduction or remove and replace.
11. **Successes in applying retroreflectivity values:** See life cycle presentation.
12. **Challenges in applying retroreflectivity values:** Contractors not meeting minimum retroreflectivity levels or not using the correct drop rate of the HRE.
13. **Comments or additional information:** [No response.]

Pennsylvania

Contact: Donald Krick, Senior Traffic Control Specialist, Bureau of Maintenance and Operations, Pennsylvania DOT, dkrick@pa.gov, 717-265-7558.

1. **Use of minimum retroreflectivity values:** Statewide.
- 1A. **Criteria to determine performance monitoring:** [No response.]
- 1B. **Identify and track pavement segments:** [No response.]
2. **Initial retroreflectivity value:**

<p><i>Hot Thermoplastic:</i> White: 300 Yellow: 250</p> <p><i>Cold Plastic:</i> White: 250 Yellow: 200</p> <p><i>Waterborne:</i> White: 250 Yellow: 165</p>	<p><i>Epoxy:</i> White: 250 Yellow: 200</p> <p><i>Preformed Thermoplastic:</i> White: 300 Yellow: 250</p>
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3. **Minimum value for a specified time period?** All pavement markings used in PA must be applied on the NTPEP test deck here in PA before it gets approved for use. There are minimums they must meet for up to three years depending on the markings.
- 3A. **Required value varies over time?** The minimum requirement lowers each year.
4. **Standard specification or special provision:**

Publication 408/2016, Construction Specifications, Pennsylvania DOT, 2016.
http://www.dot.state.pa.us/public/PubsForms/Publications/Pub_408/408_2016/408_2016_IE/408_2016_IE.pdf

Sections of the agency's Construction Specifications that relate to pavement marking include:

- Section 960, Hot Thermoplastic Pavement Markings—see page 690 of the PDF.
- Section 961, Cold Plastic Pavement Markings or Legends—see page 692 of the PDF.
- Section 962, Waterborne Pavement Markings—see page 693 of the PDF.
- Section 964, Epoxy Pavement Markings—see page 697 of the PDF.

- Section 965, Preformed Thermoplastic Pavement Markings—see page 700 of the PDF.

Durable Pavement Markings, Test Deck Specification, Pennsylvania DOT, February 2009.

See [Appendix D](#).

From the scope:

This specification covers the evaluation of the following retroreflective durable pavement marking materials that are applied on the National Transportation Product Evaluation Program (NTPEP) test deck conducted in Pennsylvania:

- Epoxy
- Cold Plastic
- Methyl-Methacrylate (MMA)
- Hot Thermoplastic
- Preformed Thermoplastic
- Polyester
- Polyurea
- Other Types – as recommended by the manufacturer unless specified by the Department

Specification for Waterborne Traffic Line Paint, Pennsylvania DOT, September 2015.

See [Appendix E](#).

This specification addresses the agency's use of fast-drying waterborne traffic line paints on bituminous and Portland cement concrete pavements.

5. **When initial retroreflectivity value taken:** Within 21 days after installation in accordance of PTM [Pennsylvania Test Method] 431. [See http://www.dot.state.pa.us/public/pdf/BOCM_MTD_LAB/PUBLICATIONS/PUB_19/PTM-431.pdf for the test method.]
6. **Measuring retained retroreflectivity:** With a 30-meter geometry retroreflectometer conforming to ASTM E-1710 [Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer; see <http://www.astm.org/Standards/E1710.htm>].
7. **Frequency of performance inspections:** This is done on the NTPEP test deck before the material is approved. It is done once a month for the first six months, then quarterly.
8. **Who conducts inspections?** [No response.]
9. **Tracking results of performance inspections:** On the test deck it is downloaded into a spreadsheet and put on the NTPEP DataMine web site [see <http://data.ntpep.org/>]. On projects it is noted in the inspector's journal.
10. **Process if failure to meet minimum requirements:** On the test deck it is not approved for use; on a project it is reapplied.
11. **Successes in applying retroreflectivity values:** It helps get the best possible markings on the highway.
12. **Challenges in applying retroreflectivity values:** Getting the contractor to duplicate the

performance of the material on the highway that it got on the test deck.

13. **Comments or additional information:** [No response.]

South Dakota

Contact: Christina Bennett, Operations Traffic Engineer, South Dakota DOT,
christina.bennett@state.sd.us, 605-773-4759.

1. **Use of minimum retroreflectivity values:** We only check retroreflectivity for waterborne paint with high-grade polymer and durable markings including epoxy, MMA and polyurea.
- 1A. **Criteria to determine performance monitoring:** By type of marking installed. We only do initial retroreflectivity values.
- 1B. **Identify and track pavement segments:** [No response.]
2. **Initial retroreflectivity value:**
 - For high-grade polymer paint:*
 - White 350 mc/m²/lux
 - Yellow 275 mc/m²/lux
 - For other durable markings:*
 - White 331 mcd/m²/lux
 - Yellow 206 mcd/m²/lux
3. **Minimum value for a specified time period?** No.
- 3A. **Required value varies over time?** No.
4. **Standard specification or special provision:** [No response.]
5. **When initial retroreflectivity value taken:** Within two and 30 days of installation.
6. **Measuring retained retroreflectivity:** It is not.
7. **Frequency of performance inspections:** [No response.]
8. **Who conducts inspections?** [No response.]
9. **Tracking results of performance inspections:** [No response.]
10. **Process if failure to meet minimum requirements:** Fails initial, contractor replaces at no cost.
11. **Successes in applying retroreflectivity values:** [No response.]
12. **Challenges in applying retroreflectivity values:** [No response.]
13. **Comments or additional information:** [No response.]

WET REFLECTIVE THERMOPLASTIC PAVEMENT MARKING, GROOVED (D-15-1013)

I. Description

This work shall consist of furnishing and installing wet night retroreflective thermoplastic pavement markings in accordance with this provision and in conformance to the dimensions and lines shown on the plans or established by the Engineer.

This specification covers wet reflective thermoplastic materials suitable for use as reflective pavement markings on asphalt pavements. A manufacturer recommended heat source fuses the markings to the asphalt pavements. Glass beads shall be pre-mixed into the material furnished. Both glass beads and wet beads shall be applied to the surface either before or after fusion to the pavement. Upon cooling, the material produces an adherent reflectorized marking of specified thickness and width, capable of resisting deformation by traffic.

The Contractor shall field verify the pavement marking quantities required for the project prior to purchasing materials. The Department will not be held responsible for the Contractor's shortage or surplus of material. The Contractor's verification of quantities and purchasing material shall not delay the project or the installation of pavement marking when required.

The thermoplastic pavement marking shall be applied in grooves cut into the surfacing. The grooves shall be made in a single pass dry cut; the equipment used shall be self vacuuming and leave the cut groove ready for thermoplastic pavement marking application. The equipment and method used shall be approved by the thermoplastic pavement marking manufacturer. The thermoplastic pavement marking shall be applied in the grooves the same day as the cut. Grooves shall be clean and dry prior to thermoplastic pavement marking application. All conflicting pavement markings which remain after application of the thermoplastic pavement markings shall be removed. The removal of conflicting, pre-existing temporary or permanent pavement marking shall be paid for with the appropriate removal pay item. The removal of conflicting temporary or permanent pavement marking placed as part of this work shall be at no cost to the Department.

Groove width:	pavement marking width + 1 inch to 2 inch max
Groove depth:	per manufacturer's recommendations
Groove length:	full length of marking + minimum required grooving transition
Groove position:	2 inches off of joint line (per plan)

Grooving of the surfacing shall be performed in accordance with the thermoplastic manufacturer's recommendations. Grooving the surfacing shall not be measured and paid for but shall be considered subsidiary to "Wet Reflective Thermoplastic Pavement Marking, Grooved".

II. Requirements

a. General

- (1) Provide the material in white and/or yellow as specified.
- (2) Provide material with a minimum thickness of 0.1 inch as supplied by the manufacturer.
- (3) Provide material that is resistant to deterioration due to exposure to sunlight, water, oil, gasoline, salt, or adverse weather conditions.
- (4) After application, the material must exhibit no appreciable deformation or discoloration, remain tack free, and not lift from the pavement under normal traffic conditions within a road temperature range of 20° to 150°F.
- (5) Provide material that is capable of conforming to pavement contours, breaks, and faults through the action of traffic at normal pavement temperatures.

b. Color

Provide yellow material that meets the minimum chromaticity coordinates in **TABLE 1**.

X	.470	.510	.485	.530
Y	.455	.485	.425	.456

c. Retroreflectivity

Required initial retroreflectance values are shown in the table below. Typical retroreflectivity is determined as the average of many readings (mcd(ft²)(fc⁻¹)) metric equivalent (mcd(m⁻²)(lux⁻¹)) as described below.

	White	Yellow
Dry (ASTM E1710)	400	325
Wet Recovery (ASTM E2177)	350	275
Wet Continuous (ASTM E2832)	100	75

- (1) Some reasonable variance should be expected (for example, application on very rough road surfaces or differences in glass beads).
- (2) The initial retroreflectance value of a single installation or unit of work shall be the average value determined according to the measurement and sampling procedures outlined in ASTM D7585, using a 30-meter (98.4 feet) retroreflectometer, except as modified below. The 30-meter retroreflectometer shall measure the coefficient of retroreflected luminance, R_L at an observation angle of 1.05 degrees and an entrance angle of 88.76 degrees. R_L shall be expressed in units of millicandelas per square foot per foot-candle [mcd(ft²)(fc⁻¹)]. The metric equivalent shall be expressed in units of millicandelas per square meter per lux [mcd(m⁻²)(lux⁻¹)].

- (3) The initial retroreflectance values of the pavement marking shall be measured no sooner than 48 hours after application, but not later than 30 days after application. The contractor shall provide an acceptable 30-meter retroreflectometer to use on the project (The retroreflectometer will remain the property of the contractor). The contractor will take measurements in the presence of the Engineer. Prior to taking measurements, the contractor shall calibrate the retroreflectometer according to the manufacturers requirements.

Measurements will be taken at equally spaced evaluation sections located by the Engineer. One evaluation section is required every 3 miles along a segment. If the last evaluation section is less than 1.5 miles, it shall be combined with the preceding section.

The evaluation sections shall be at least 400 ft in length and have a minimum of 10 readings taken over the length of the section.

All measurements shall be made in the direction of travel. On centerlines of undivided highways, measurements shall be taken in both directions in each location and averaged for one measurement.

These measurements shall be taken for each color line in the evaluation section.

The Department will do verification testing on the evaluation section. When the average of the readings for an evaluation section fall below the minimum, the entire section represented by those readings will be further evaluated by the Engineer and may be subject to removal and replacement.

- (4) The Department may elect to determine wet retroreflectance values measured under a "condition of continuous wetting" (simulated rain) in accordance with ASTM E2832. To reduce variability between measurements, the test method shall be performed in a controlled laboratory environment while the marking is positioned with a 3 to 5 degree lateral slope. Measurements shall be reported as the average of the minimum of three locations. Samples of the completed finished product shall be applied to flat panels during application and brought back to the lab for testing. When such samples are taken, the Department will furnish the panels.

d. Dimensions

The pavement markings shall be placed only on properly prepared surfaces and at the widths and patterns as designated in the contract. The markings shall be applied in accordance with the "Manual on Uniform Traffic Control Devices" and in accordance with the Engineer's plans.

Any markings that are found to be 0.5 inches less than the width shown in the plans shall be removed and replaced by the contractor.

e. Thermoplastic Material and Premix Beads.

- (1) Provide thermoplastic material that complies with AASHTO M 249 with exception of the relevant differences due to the material being supplied in a preformed state.
- (2) All pigments must be heavy metal free, including, but not restricted to lead, cadmium, and mercury.

f. Glass Beads for Drop-on Application.

Provide glass beads that are specifically manufactured to be compatible with the thermoplastic system, and comply with AASHTO M 247, Type I.

g. Wet Reflective Media.

Provide wet reflective media approved by the manufacturer. The wet reflective media that qualify for use are shown in the NDR Approved Products List.

III. Test Methods

- a. Thermoplastic Material and Premix Beads. AASHTO T 250**
- b. Glass Beads for Drop-On Application. AASHTO M 247**

IV. Observation Period

Following initial completion of all pavement marking, there will be a 180-day observation period before final acceptance. During the observation period, the Contractor, at no expense to the Department of Roads, shall replace any markings that the Engineer determines are not performing satisfactorily due to defective materials and/or workmanship in manufacture and/or application. At the end of the observation period the minimum required retention percentage for marking installed shall be 90%.

Determination of Percentage Retained - The percentage retained shall be calculated as the nominal area of the strip less the area of loss divided by the nominal area and expressed as a percentage of the nominal area. A claim, made by the State against the Contractor, shall be submitted to the Contractor in writing within 30 days after the 180-day observation period. When such a claim is made prior to August 1, the replacement material shall be installed during that same construction season. Replacement material for any claim after August 1 shall be installed prior to June 1 of the following year. Marking replacement shall be performed in accordance with the requirements specified herein for the initial application, including but not limited to surface cleaning, sealer application, etc.

Final acceptance of all marking will include an inspection of the appearance of the markings during daylight and darkness. Any markings that fail to have a satisfactory appearance during either period, as determined by the Engineer, shall be reapplied at no expense to the Department of Roads.

Final acceptance of the pavement marking will be: (1) 180 days after the initial completion of all work, or (2) upon completion of all corrective work, whichever occurs last.

V. Certification of Compliance

The Contractor shall furnish a manufacturer's certification that the material complies with the provisions of this specification.

VI. Contract Units and Basis for Payment

- a. Linear pavement markings will be measured in linear feet complete-in-place for the width specified.

Subsection 423.05 of the 2007 Standard Specifications is amended to include the item: "Wet Reflective Thermoplastic Pavement Marking, Grooved". The price shall be full compensation for grooving the pavement surface, furnishing and applying all markings, and for all materials, labor, tools, equipment and incidentals necessary to complete the work.

Payment will be made under:

<u>Pay Item</u>	<u>Pay Unit</u>
____ Wet Reflective Thermoplastic Pavement Marking, Grooved	Linear Feet

WET REFLECTIVE POLYUREA PAVEMENT MARKING, GROOVED (D-17-1013)

I. Description

This work shall consist of furnishing and installing wet night retroreflective polyurea pavement markings in accordance with this provision and in conformance to the dimensions and lines shown on the plans or established by the Engineer.

The wet reflective polyurea marking material shall be applied by spray method onto asphaltic cement concrete and Portland cement concrete surfaces. Following an application of glass beads or black aggregate, and upon curing, the resulting marking shall be an adherent reflectorized stripe of the specified thickness and width that is capable of resisting deformation by traffic.

The Contractor shall field verify the pavement marking quantities required for the project prior to purchasing materials. The Department will not be held responsible for the Contractor's shortage or surplus of material. The Contractor's verification of quantities and purchasing material shall not delay the project or the installation of pavement marking when required.

The polyurea pavement marking shall be applied in grooves cut into the surfacing. The grooves shall be made in a single pass dry cut; the equipment used shall be self-vacuuming and leave the cut groove ready for polyurea pavement marking application. The equipment and method used shall be approved by the polyurea pavement marking manufacturer. The polyurea pavement marking shall be applied in the grooves the same day as the cut. Grooves shall be clean and dry prior to polyurea pavement marking application. All conflicting pavement markings which remain after application of the polyurea pavement markings shall be removed. The removal of conflicting, pre-existing temporary or permanent pavement marking shall be paid for with the appropriate removal pay item. The removal of conflicting temporary or permanent pavement marking placed as part of this work shall be at no cost to the Department.

Groove width: pavement marking width + 1 inch to 2 inch maximum
Groove depth: per manufacturer's recommendations to a minimum of 60 mils
Groove length: full length of marking + required grooving transition
Groove position: 2 inches off of joint line (per plan)

Grooving of the surfacing shall be performed in accordance with the polyurea manufacturer's recommendations. Grooving the surfacing shall not be measured and paid for but shall be considered subsidiary to "____ Wet Reflective Polyurea Pavement Marking, Grooved".

II. Materials

A. Polyurea

Composition Requirements:

Composition requirements are per manufacturer's specifications. The Wet Reflective Polyurea Pavement Markings approved for use are shown on the NDR Approved Products List. Markings which have not been previously approved by the Department will not be permitted on the project until approved by the Traffic Engineer.

Properties:

1. Color and Weathering Resistance: The mixed polyurea compound, white, yellow and black, when applied to a 3" x 6" aluminum panels at 15±1 mil in thickness with no glass beads or elements and exposed for 500 hours in a Q.U.V. Environmental Testing Chamber, as described in ASTM-G154, Cycle #1, shall conform to the following minimum requirements. The color of the white polyurea system shall not be darker than Federal Standard No. 595A-17778. The color of the yellow polyurea system shall conform to Federal Standard No. 595A-13538. The color of the black polyurea system shall conform to Federal Standard No. 595A-17038.
2. Track-Free Time (Laboratory): When tested in accordance with ASTM D 711, the polyurea marking material shall reach a track-free condition in 10 minutes or less for a 15 mil thickness. This test shall be performed with AASHTO Type 1 beads coated at a rate of 0.099 pounds per square foot. The track-free time shall not increase substantially with decreasing temperature.
3. Adhesion to Concrete: The polyurea coating, when tested according to ACI Method 503, shall have such a high degree of adhesion to the specified concrete surface that there shall be a 100% concrete failure in the performance of this test. The prepared specimens shall be conditioned at room temperature (75°± 2° F) for a minimum of 24 hours and maximum of 72 hours prior to the performance of the tests indicated.
4. Adhesion to Asphalt: The polyurea coating, when tested according to ACI Method 503, shall have such a high degree of adhesion to the specified asphalt surface that there shall be a 100% asphalt failure in the performance of this test. The prepared specimens shall be conditioned at room temperature (75°± 2° F) for a minimum of 24 hours and maximum of 72 hours prior to the performance of the tests indicated.

B. Reflective Media

The reflective media application shall incorporate a double drop technique to maximize wet night reflectivity and color. The reflective media used shall ensure the wet reflective polyurea pavement markings meet the retroreflectance performance requirements in Section II.D.3. The glass beads for drop-on application shall conform to the following requirements *or be an approved equivalent*.

1. Glass Beads

The required glass beads shall be a 60/40 blend (60% sinkers and 40% floaters) of AASHTO M 247-81 Type I gradation 1.5 index glass beads. The glass beads shall have a minimum of 70% Rounds as measured according to ASTM D1155. Crush Resistance shall be measured according to the procedures of ASTM D1213 and shall be a minimum of 30 pounds retained on US #40 Mesh.

Acid Resistance: A sample of glass beads supplied by the manufacturer shall show resistance to corrosion of their surface after exposure to a 1% solution (by weight) of sulfuric acid. The 1% acid solution shall be made by adding 5.7 cc of concentrated acid into 1000 cc of distilled water. CAUTION: Always add the concentrated acid into the water, not the reverse. The test shall be performed as follows:

Take a 1" x 2" sample, adhere it to the bottom of a glass tray and place just enough acid solution to completely immerse the sample. Cover the tray with a piece of glass to prevent evaporation and allow the sample to be exposed for 24 hours under these conditions. Then decant the acid solution (do not rinse, touch, or otherwise disturb the bead surfaces) and dry the sample while adhered to the glass tray in a 150° F (66° C) oven for approximately 15 minutes. Microscopic examination (20X) shall show not more than 15% of the beads having a formation of very distinct opaque white (corroded) layer on their entire surface.

2. Wet Reflective Media

Wet reflective media shall be approved for use by the polyurea manufacturer. The Wet Reflective Media approved for use are shown in the NDR Approved Products List.

C. Non-reflective Media

Black aggregate shall be broadcast to saturation on all black lines to provide a matte, non-reflective finish. The black aggregate shall be either a fine or medium gradation.

D. Finished Markings

Because of normal variances in road surfaces, application processes and measurement, the properties of markings made from the materials specified herein will vary from one installation to the next. When the materials are applied according to the specifications in Section III, they shall be capable of forming markings with the following reproducibility of properties:

1. On-the-road Track-Free Time: When installed at 77° F and at a wet film thickness of 15±1 mils, the markings shall reach a no-track condition in less than 10 minutes. Track-free shall be considered as the condition where no visual deposition of the polyurea marking to the pavement

surface is observed when viewed from a distance of 50 feet, after a free-rolling traveling vehicle's tires have passed over the line. The track-free time shall not increase substantially with decreasing temperature.

2. Skid Resistance: The average initial skid resistance shall be 45 BPN or greater when tested according to ASTM E303.
3. Retroreflectance – Required initial retroreflectance values are shown in the table below. Typical retroreflectivity is determined as the average of many readings ($\text{mcd}(\text{ft}^{-2})(\text{fc}^{-1})$) metric equivalent ($\text{mcd}(\text{m}^{-2})(\text{lux}^{-1})$) as described below.

Average Minimum Initial Retroreflectance		
	White	Yellow
Dry (ASTM E1710)	500	350
Wet Recovery (ASTM E2177)	350	275
Wet Continuous (ASTM E2832)	100	75

- 3.1.1 Some reasonable variance should be expected (for example, application on very rough road surfaces or differences in glass beads).
- 3.1.2 The initial retroreflectance value of a single installation or unit of work shall be the average value determined according to the measurement and sampling procedures outlined in ASTM D7585, using a 30-meter (98.4 feet) retroreflectometer, except as modified below. The 30-meter retroreflectometer shall measure the coefficient of retroreflected luminance, R_L at an observation angle of 1.05 degrees and an entrance angle of 88.76 degrees. R_L shall be expressed in units of millicandelas per square foot per foot-candle [$\text{mcd}(\text{ft}^{-2})(\text{fc}^{-1})$]. The metric equivalent shall be expressed in units of millicandelas per square meter per lux [$\text{mcd}(\text{m}^{-2})(\text{lux}^{-1})$].
- 3.1.3 The initial retroreflectance values of the pavement marking shall be measured no sooner than 48 hours after application, but not later than 30 days after application. The contractor shall provide an acceptable 30-meter retroreflectometer to use on the project (The retroreflectometer will remain the property of the contractor). The contractor will take measurements in the presence of the Engineer. Prior to taking measurements, the contractor shall calibrate the retroreflectometer according to the manufacturer's requirements.

Measurements will be taken at equally spaced (or nearly so) test areas located by the Engineer in each evaluation section. An evaluation section is defined as a 3 mile (or major fraction) portion of a segment. If the last evaluation section is less than 1.5 miles in length, it shall be combined with the preceding section.

The test areas shall be at least 400 ft. in length and a minimum of 10 readings shall be taken over the length of each test area.

All measurements shall be made in the direction of travel. On centerlines of undivided highways, measurements shall be taken in both directions in each test area and averaged to determine the value of that color line in that test area.

Measurements shall be taken for each type and color of line in the evaluation section.

Individual symbols and legends will be treated as separate evaluation sections. Three (3) readings shall be taken on each symbol to determine the average retroreflectance value for the symbol.

The Department will do verification testing. When the average of the readings for an evaluation section fall below the minimum, the entire section represented by those readings will be further evaluated by the Engineer and may be subject to removal and replacement.

- 3.1.4 The Department may elect to determine wet retroreflectance values measured under a "condition of continuous wetting" (simulated rain) in accordance with ASTM E2832. To reduce variability between measurements, the test method shall be performed in a controlled laboratory environment while the marking is positioned with a 3 to 5 degree lateral slope. Measurements shall be reported as the average of the minimum of three locations. Samples of the completed finished product shall be applied to flat panels during application and brought back to the lab for testing. When such samples are taken, the Department will furnish the panels.

III. Application

The Contractor shall furnish equipment and apply the materials according to the following specifications:

A. Equipment

Application equipment shall be capable of producing markings that meet the specifications of the manufacturer's listed on the NDR Approved Products List for Wet Reflective Polyurea Pavement Marking.

At any time throughout the duration of the project, the Contractor shall provide free access to his application equipment for inspection by the Engineer, his authorized representative or a materials representative.

When black and white polyurea are applied together to create a contrast pattern, they shall be applied from one truck in a single pass operation.

B. Application Conditions:

1. **Moisture:** The markings shall only be applied during conditions of dry weather and when the pavement surface is dry and free of moisture.
2. **Air Temperature:** The markings shall only be applied when road and air temperatures are above 40 degrees F, unless manufacturer's guidelines state otherwise.
3. **Surface Preparation:** Marking operations shall not begin until applicable surface preparation work is completed and approved by the Engineer.
 - 3.1 Prior to applying the markings, the Contractor shall remove any remaining existing markings to expose a minimum of 80% of the pavement surface.
 - 3.2 Prior to applying the markings, the Contractor shall remove all curing compounds on new Portland cement concrete surfaces.
 - 3.3 Prior to applying the markings, the Contractor shall remove all dirt, sand, dust, oil, grease and any other contaminants from the road surface.
 - 3.4 Application over temporary paint is not acceptable.
4. **Dimensions:** The pavement markings shall be placed only on properly prepared surfaces and at the widths and patterns as designated in the contract. The markings shall be applied in accordance with the "Manual on Uniform Traffic Control Devices" and in accordance with the Engineer's plans.

Any markings that are found to be 0.5 inches less than the width shown in the plans shall be removed and replaced by the contractor.
5. **Other Restrictions:** The Engineer and/or Contractor shall determine further restrictions and requirements of weather and pavement conditions necessary to meet the all other application specifications and produce markings that perform to the satisfaction of the Engineer.
6. **Binder Thickness:** The polyurea binder (mixed Part A and Part B) coating shall be applied at rates to achieve minimum uniform wet thicknesses as follows:

Surface Type	Recommended Polyurea Pavement Marking Thickness (1 inch=1000 mils)
Existing Smooth Asphalt or Concrete Surface	20±2 mils
New Concrete Surface ¹	20±2 mils
New Asphalt Surface (Standard Asphalt Mix)	20±2 mils
Open Grade Friction Course (OGFC) or Stone Matrix Asphalt (SMA) ²	25±2 mils
Rough Concrete or Asphalt	22±2 mils
Concrete or Asphalt after Grinding Off Pavement Markings ³	22±2 mils

¹ Use thicker binder (20 mils) on new concrete surfaces with heavy tines.

² Very large aggregate sizes for open grade friction course or stone matrix asphalt mixes may require a thickness of 25 mils for proper coverage.

³ Pavement marking thickness determined by the type of surface and roughness/texture created from grinding operation.

7. **Reflective Media Application:** The Contractor shall ensure that the reflective media are properly set in the polyurea coating so that their exposed portions are free of polyurea coating material. The specified reflective media shall be dropped per the manufacturer's specified rates to achieve their recommended coating weights:
8. **Volumetric Proportioning:** The Contractor shall ensure proper proportioning as required by manufacturer's specifications and mixing of the polyurea components so that the markings are adequately hardened throughout and are free of soft or uncured material. Typically, such areas will darken over time from dirt and tire residue.
9. **Overspray:** The Contractor shall ensure the polyurea coating does not exhibit excessive overspray.
10. **Adhesion:** The Contractor shall ensure that the polyurea coating is well adhered to the road surface, and that the reflective media are well adhered to the binder.

IV. Observation Period

Following initial completion of all pavement marking, there will be a 180-day observation period before final acceptance. During the observation period, the Contractor, at no expense to the Department of Roads, shall replace any marking that the Engineer determines are not performing satisfactorily due to defective materials and/or workmanship in manufacture and/or application. At the end of the observation period the minimum required retention percentage for marking installed shall be 90%.

Determination of Percentage Retained - The percentage retained shall be calculated as the nominal area of the strip less the area of loss divided by the nominal area and expressed as a percentage of the nominal area. A claim, made by the State against the Contractor, shall be submitted to the Contractor in writing within 30 days after the 180-day observation period. When such a claim is made prior to August 1, the replacement material shall be installed during that same construction season. Replacement material for any claim after August 1, shall be installed prior to June 1, of the following year. Marking replacement shall be performed in accordance with requirement specified herein for the initial application, including but not limited to surface cleaning, sealer application, etc.

Final acceptance of all marking will include an inspection of the appearance of the markings during daylight and darkness. Any markings that fail to have a satisfactory appearance during either period, as determined by the Engineer, shall be reapplied at no expense to the Department of Roads.

Final acceptance of the pavement marking will be: (1) 180 days after the initial completion of all work, or (2) upon completion of all corrective work, whichever occurs last.

V. Contract Units and Basis for Payment

- A. Linear pavement markings will be measured in linear feet complete-in-place for the width specified.
- B. Arrows and Legends are measured by the each.

Subsection 423.05 of the Standard Specifications is amended to include the item: " Wet Reflective Polyurea Pavement Marking, Grooved". Payment shall be full compensation for grooving the pavement surface, furnishing and applying all markings, and for all materials, labor, tools, equipment and incidentals necessary to complete the work.

Payment will be made under:

Pay Item	Pay Unit
___ Wet Reflective Polyurea Pavement Marking, Grooved	Linear Feet
___ Wet Reflective Polyurea Pavement Marking, Grooved	Each

Payment is full compensation for all work prescribed in this Section.

Commonwealth of Pennsylvania
 Department of Transportation

DURABLE PAVEMENT MARKINGS

February 23, 2009

1. SCOPE

This specification covers the evaluation of the following retroreflective durable pavement marking materials that are applied on the National Transportation Product Evaluation Program (NTPEP) test deck conducted in Pennsylvania:

- Epoxy
- Cold Plastic
- Methyl-Methacrylate (MMA)
- Hot Thermoplastic
- Preformed Thermoplastic
- Polyester
- Polyurea
- Other Types – as recommended by the manufacturer unless specified by the Department

2. MATERIALS

2.1 Color. The pavement markings shall be available in both white and yellow. Upon product acceptance, the initial unbeaded, finished colors shall satisfy the following chromaticity coordinates:

Table 1. Chromaticity Coordinates

Color	1		2		3		4	
	X ₁	Y ₁	X ₂	Y ₂	X ₃	Y ₃	X ₄	Y ₄
White	0.330	0.370	0.355	0.345	0.310	0.300	0.285	0.325
Yellow	0.515	0.465	0.505	0.430	0.440	0.415	0.420	0.443

2.2 Environmental Issues. Each manufacturer shall formulate all pavement-marking materials based on their specifications except that the marking materials shall have pigments that during the handling, application and removal of these materials, worker exposure to these products shall not exceed chemical exposure limits as indicated in OSHA 29 CFR 1910. The composition of these products shall be compatible with all conventional application equipment available. The pavement marking materials shall be free from all dirt and foreign objects.

2.3 Glass Beads. Apply reflective glass beads Type A, B, C, or D conforming to Department’s Specification Publication 408, Section 1103.14. Rates and material

combinations shall be as tested by Department forces on an applicable AASHTO/NTPEP test deck sited in Pennsylvania.

3. **APPLICATION**

3.1 General. Pavement markings shall be readily applied by the equipment or methods recommended by the manufacturer.

3.2 Glass Beads. Except for cold plastic tape markings, the application rate of glass beads by drop-on or pressure methods shall be as recommended by the manufacturer unless specified by the Department by prior AASHTO/NTPEP testing.

3.3 Application Thickness. The installed thickness of durable markings shall be as follows:

- Epoxy – 20 mils to 30 Mils
- Cold plastic – 60 mils to 90 Mils
- MMA – 20 mils to 30 Mils
- Hot Thermoplastic – 90 mils to 120 Mils
- Hot Thermoplastic (spray) – 30 mils to 50 Mils
- Preformed Thermoplastic – 90 mils to 125 Mils
- Polyester – 15 mils to 20 Mils
- Polyurea – 20 mils to 30 Mils
- Other types – as recommended by the manufacturer unless specified by the Department

4. **TESTING**

4.1 Number of Test Sites. For testing purposes, the manufacturer or manufacturer's representative shall install test lines on both concrete and bituminous roadways as required by NTPEP policies. Separate test lines shall be installed for each color of each material. Pavement markings installed on concrete and bituminous surfaces will be evaluated and approved separately for each type and color based on the requirements of the Department's Test Deck specifications.

4.2 Retroreflectivity Readings. Retroreflective readings of each line will be taken once a month during the first year after installation and quarterly during the next 2 years. Retroreflectivity will be measured in millicandelas per square meter per lux (mcd/m²/lux) using a 30-meter Department retroreflectometer. Readings will be made adjacent to the centerline or lane line (outside the normal travel path of vehicles) and in the wheel path.

4.3 Durability Ratings. Durability readings will be evaluated subjectively on a scale of "0" to "10," where "0" means that the marking does not exist, a "10" means that the marking is completely intact, and intermediate values such as a "5" means that the marking is only 50 percent present.

5. APPROVAL

5.1 Types of Approvals. Materials that satisfy the 2-year minimum retroreflectivity and durability values after 2 years on the test deck will be given a “provisional approval” for sale and use in the Commonwealth (materials may also be given “provisional approval” after the second winter but before the full 2 years if the material satisfies the requirements in the row titled “After 2nd winter” in Table 2), and after 3 years on the test deck will be given full approval for sale and use in the Commonwealth.

- Materials which meet or exceed the retroreflectivity (RR) and durability (D) values as included in Table 2 at the centerline location will be approved for use as centerlines, lane lines and edge lines.
- Materials which meet or exceed the retroreflectivity (RR) and durability (D) values as included in Table 2 at both the centerline and wheel track locations will also be approved for use as crosswalks, stop lines, legends and crosshatching.

Table 2. Minimum Retroreflectivity and Durability Values

Duration	Centerline Location	Wheel Track Location
Initial	RR = As specified in Pub 408* D = 10	RR = As specified in Pub 408* D = 10
After 2nd winter**	RR = 165 mcd/m ² /lux for white 155 mcd/m ² /lux for yellow D = 8	RR = 120 mcd/m ² /lux for white 100 mcd/m ² /lux for yellow D = 7
2 years	RR = 150 mcd/m ² /lux for white 135 mcd/m ² /lux for yellow D = 8	RR = 100 mcd/m ² /lux for white 90 mcd/m ² /lux for yellow D = 7
3 years	RR = 100 mcd/m ² /lux for white 85 mcd/m ² /lux for yellow D = 6	RR = 70 mcd/m ² /lux for white 60 mcd/m ² /lux for yellow D = 6

* Materials not listed in Pub 408 shall have an initial minimum retroreflectivity of 300 mcd for white and 250 mcd for yellow.

** These values are only applicable for issuing a provisional approval.

5.2 Changes in Composition. Manufacturers must notify the Department of any change that has been made to an approved material, physical or chemical, so that the Department can determine if retesting is necessary or if the approval should be revised.

James P. Tenaglia, P.E., Chief
 Risk Management and Administrative Services Division
 Bureau of Highway Safety and Traffic Engineering

Commonwealth of Pennsylvania
Department of Transportation

SPECIFICATION FOR WATERBORNE TRAFFIC LINE PAINT

September 4, 2015

1. **SCOPE**

1.1 Scope. This specification covers fast-drying waterborne traffic line paints for use on bituminous and Portland cement concrete pavements. When used, paints will be made retroreflectorized for night visibility by adding reflective spheres under pressure before the paint dries or sets.

2. **REQUIREMENTS**

2.1 General. Traffic paint shall consist of a ready-mixed pigmented binder in a one-package system. When applied at a wet-film thickness of 15 mils, the paint shall be suitable for application on all types of roadway surfaces.

2.2 Pigments. Except for the yellow pigment, the manufacturer may use any combination of pigments provided the finished paint meets all the requirements specified herein. Suppliers may use any organic yellow pigment provided it does not contain any of the metals listed in the Environmental Protection Agency Code of Federal Regulation 40, Section 261.24. Sufficient suspending and dispersing agents shall be used to prevent excessive settling.

2.3 Composition. The manufacturer may use any combination of ingredients provided the finished paint satisfies all of these specifications. Sufficient quantity of anti-skinning agents shall be used to prevent skinning, as specified herein. Adequate resin solids, compatible thinners and driers, if necessary, shall be used to meet requirements of Table 1.

2.4 Paint Requirements. The mixed paint shall meet the requirements specified in Table 1.

2.5 Retroreflectivity. The minimum initial retroreflectivity is 250 mcd/m²/lux for white and 165 mcd/m²/lux for yellow. The minimum retroreflectivity after 12 months is 150 mcd/m²/lux for white and 100 mcd/m²/lux for yellow. However, the Department will review the results of each test deck to determine the minimum value in effect for that deck, in order to approve only the better-performing materials and to ensure competition in the bidding process after 12 months.

2.6 Durability. A minimum durability rating of “7” in the skip line area and “6” in the wheel paths after 12 months. The rating system used will be as indicated by NTPEP procedures.

2.7

Table 1
Requirements of Mixed Paints

Characteristics	Requirement	ASTM	Reference Paragraph
Consistency, KU *	80-95	D 562	
Weight per gallon, lbs **		D 1475	
Vehicle Solids ***		D 2369	
Contrast Ratio (0.015 blade)	0.98 min.	D 2805	
Directional Reflection (0.015 blade) White Yellow	84 min. 54 min.	E 1349	
Color			3.2
Condition of Container, Minimum Rating	8	D 869	3.3
Skinning	Passes		3.4
Heat Stability, KU	± 5 KU of initial		3.5
Freeze-Thaw Stability, KU	± 5 KU of initial		3.6
No-Track Time (Field)	90 sec. or less		3.7
No-Track Time (Lab)		D 711	3.8
Miscellaneous Tests			3.9

* Initial mean value shall fall within 80-95 KU tolerance. QC/QA tolerances of an approved material shall fall within the range set in D 562 during the lab analysis portion of the NTPEP evaluation.

** QC/QA tolerances of an approved material shall fall within a range set by D 1475, established during the lab analysis portion of the NTPEP evaluation.

*** QC/QA tolerances of an approved material shall fall within a range set by D 2369, established during the lab analysis portion of the NTPEP evaluation.

3. TESTING

3.1 ASTM Standards. The tests shall be conducted in accordance with ASTM Standards, except as otherwise specified (see Table 1).

3.2 Color. The color of the dry paint shall satisfy the appropriate chromaticity coordinates indicated in Table 2.

Table 2
Chromaticity Coordinates

Color	1		2		3		4	
	x	y	x	y	x	y	x	y
White	0.330	0.370	0.355	0.345	0.310	0.300	0.285	0.325
Yellow	0.515	0.465	0.505	0.430	0.440	0.415	0.420	0.443

3.3 Condition in Containers. The paint shall show no curdling, livering, caking, lumps, skins or color separation. Any settling that has occurred in containers opened within 45 days after receipt must be able to be mixed to a smooth homogeneous state within 5 minutes. This requirement applies to both test samples that are mixed with spatulas, and to paint in 275-gallon intermediate bulk containers that are mixed with air-driven industrial mixers.

3.4 Skinning. The paint shall not skin within 48 hours in a three-quarter-filled, tightly closed container.

3.5 Heat Stability. Put 450 ml of paint in a 473 ml (1 pint) lined container, close the container, seal it with tape and put it in an oven maintained at $60^{\circ} \pm 1^{\circ}$ C for 1 week. Equilibrate the paint at $25^{\circ} \pm 1^{\circ}$ C and mix thoroughly with gently stirring. Perform the consistency test as specified in ASTM D 562. Consistency shall not vary more than ± 5 KU from the initial viscosity.

3.6 Freeze-Thaw Stability. Put 450 ml of paint in a 473 ml (1 pint) lined container, close the container, invert, and place in a chamber maintained at $-10^{\circ} \pm 1^{\circ}$ C. Remove the container after 16 hours and maintain at $25^{\circ} \pm 1^{\circ}$ C for 8 hours. Repeat this procedure four more times. At the completion of the freeze-thaw cycles, equilibrate the paint at $25^{\circ} \pm 1^{\circ}$ C, mix thoroughly with gentle stirring, and examine for smoothness and uniformity. Repeat the consistency tests as specified in ASTM D 562. Consistency shall not vary more than ± 5 KU. The paint shall show no evidence of coagulation or breaking of the emulsion.

3.7 No-Track Time (Field). The reflectorized line, when applied at 15 ± 1 mil wet film thickness with glass spheres applied at rate of 6 pounds per gallon of paint, shall have a no-track time of 90 seconds or less with a maximum paint temperature at the guns of 54° C. The maximum no-track time shall not be exceeded when the pavement temperature is between 10° C and 50° C with the relative humidity less than 70 percent and the pavement is dry. The no-track time shall be determined by passing over an applied test line at approximately 30 degrees with a standard size passenger car or pick-up truck. A line showing no visual deposition of the paint to the pavement surface when viewed from a distance of 15.2 m (50 feet) shall be considered as conforming to the dry-time requirements. Verification of this property can be performed at any time, i.e., prior to or after award of a contract.

3.8 Alternate No-Track Time (Lab). Draw down paint on clean glass plate at various depths using an adjustable doctor blade. Determine which wet film thickness yields a completed dry film thickness of 7 to 8 mils. Fill the bottom of a Paul N. Gardner Co. test chamber, Model WE-HTAB-176, with 6 to 12 mm of water. Close all ports and the door to allow equilibrating overnight. By carefully opening and closing the ports, establish a relative humidity of 90 ± 3 percent inside the chamber. Record temperatures and relative humidity inside and outside the chamber. On clean glass, draw down two test panels of the predetermined wet film thickness that yields a dry film thickness of 7 to 8 mils. Promptly place the wet films in the test chamber and maintain the relative humidity of 90 ± 3 percent. Touch the films at 15-minute intervals until the finger does not pick up wet paint. Then begin dry-through testing outside the chamber at 15-minute intervals. The film is dry through if it does not distort from a 90° -thumb twist without pressure on the film. Record temperatures, relative humidity, and times. Measure the dry thickness of the paint. A control or standard paint should be tested every day that dry-through time tests are conducted.

3.9 Miscellaneous Tests. Samples of shipment may be subjected to other tests such as x-ray analysis, infrared and/or ultraviolet spectral analysis.

4. APPROVAL

4.1 Test Deck. Manufacturers are responsible for installing test lines on the National Transportation Product Evaluation Program (NTPEP) test deck conducted in Pennsylvania or Minnesota.

4.2 Approval. At the end of one year, the Department will evaluate the results of laboratory and test deck data. This information will be reviewed for each material by color and roadway surface to determine compliance with this specification. Material must meet or exceed the specification requirements on both bituminous and portland cement concrete surfaces on the same NTPEP test deck to be approved. Approved paint formulas will

remain active for a period of approximately 4 years; afterwards the paint will need to be retested.

5. **DEPARTMENT PURCHASES (INFORMATION ONLY).**

5.1 Price Adjustment Factor. In order to emphasize quality, the Department will apply a Price Adjustment Factor (PAF) as a multiplier to each paint bid price prior to selecting the “low bid.” The Department’s formula for statewide bids for “white and yellow traffic line paint,” i.e., Contract #8010-04, is as follows:

$$\text{PAF} = [1000/((0.85\text{RB} \times \text{DB}) + (0.15\text{RC} \times \text{DC}))]^{0.75}$$

where:

RB = average retroreflectivity on bituminous pavements after 12 months on the test deck

DB = durability rating in wheel path on bituminous pavement after 12 months on the test deck

RC = average retroreflectivity on Portland cement pavements after 12 months on the test deck

DC = durability rating in wheel path on Portland cement after 12 months on the test deck



Robert Pento, P.E., Chief
Traffic Engineering and Permits Sections
Bureau of Maintenance and Operations