Evaluation of Wet-Nighttime Delineation
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EVALUATION OF WET-NIGHTTIME DELINEATION

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and

Federal Highway Administration
U.S. Department of Transportation

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### Abstract

The objective of the research was to evaluate the alternative methods which could potentially provide effective and durable delineation of roadways during wet-nighttime conditions. Following is a summary of conclusions for future procedures and materials which should be considered as a method to provide effective lane delineation during wet-nighttime conditions.

- Snowplowable raised pavement markers should continue to be used on interstates and parkways. The installation process must ensure the markers are not placed on or adjacent to the pavement joint.
- Lenses in the steel casting raised pavement markers should be replaced on a three-year cycle. The condition of the castings should be inspected as part of this process.
- The pavement condition adjacent to the raised pavement marker castings should be monitored to ensure there is no failure adjacent to the casting.
- Evaluation of the use of a recessed pavement marker should continue.
- Rumble stripes (painting edge line and centerline markings across a milled rumble strip) should be routinely used on resurfacing projects on rural, two-lane roads. Guidelines have been developed for the use of an edge line and/or centerline rumble stripe related to the pavement width.
- Evaluation of the grooved and inlay installations of the wet-reflective paint, tape and thermoplastic material should continue.
- Current research for an alternative to the current “bare pavement” policy (which involves use of steel snowplow blades with full weight) should be continued. Alternatives to the current policy include use of an alternative snowplow blade or a method of reducing the weight of the plow blade applied to the pavement.
EXECUTIVE SUMMARY

The objective of the research was to evaluate the alternative methods which could potentially provide effective and durable delineation of roadways during wet-nighttime conditions.

Following is a summary of conclusions for future procedures and materials which should be considered as a method to provide effective lane delineation during wet-nighttime conditions.

• Snowplowable raised pavement markers should continue to be used on interstates, parkways, and other four-lane highways. The installation process must ensure the markers are not placed on or adjacent to the pavement joint.
• Lenses in the steel casting raised pavement markers should be replaced on a three-year cycle. The condition of the castings should be inspected as part of this process.
• The pavement condition adjacent to the raised pavement marker castings should be monitored to ensure there is no failure adjacent to the casting.
• Evaluation of the use of a recessed pavement marker (as an alternative to the steel casting marker) should continue.
• Rumble stripes (painting edge line and centerline markings across a milled rumble strip) should be routinely used on resurfacing projects on rural, two-lane roads. Guidelines have been developed for the use of an edge line and/or centerline rumble stripe related to the pavement width.
• Evaluation of the grooved and inlay installations of the wet-reflective paint, tape and thermoplastic material should continue.
• The effectiveness of surface-applied pavement marking materials which have the potential to provide wet-nighttime delineation is inhibited due to snowplow damage. Current research for an alternative to the current “bare pavement” policy (which involves use of steel snowplow blades with full weight) should be continued. Alternatives to the current policy include use of an alternative snowplow blade or a method of reducing the weight of the plow blade applied to the pavement.
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1.0 INTRODUCTION

An effective method of providing durable and effective roadway delineation during wet-nighttime conditions has been the source of research studies in Kentucky and many other states for decades. Typical traffic paint has not been effective in providing lane delineation at night during wet pavement conditions.

Past research has evaluated various types of marking materials and raised pavement markers. Snowplowable raised pavement markers have been used in Kentucky for many years as a method of providing wet-nighttime delineation; however, there have been problems with the durability of the castings if the adjacent pavement is not maintained and with their effectiveness when their lenses have not been maintained.

The objective of this research is to evaluate alternative methods which could potentially provide effective lane delineation of roadways during wet-nighttime conditions.

2.0 BACKGROUND

The first documented attempt in Kentucky to provide improved wet-nighttime delineation was the use of raised pavement markers (RPM) (1). The initial 1975 study found that RPM were effective under wet-nighttime conditions. The study resulted in extensive use of surface-mounted RPM as a supplement to painted lane lines. The effectiveness of RPM was confirmed in a 1981 study (2). However, due to extensive snowplow damage to these markers (after the use of rubber-tipped snowplow blades was discontinued) an evaluation of snowplowable RPM was conducted in 1982 (3). The evaluation of several potential types of RPM resulted in the recommendation that the Stimsonite 96 (steel casting) marker and a recessed marker design should be used. The first large scale installations of these two types of snowplowable RPM were completed in 1984 and 1985. An evaluation of these installations found they were effective with the recommendation that the steel casting type of marker should continue to be used (4).

Use of the snowplowable RPM continued in Kentucky for many years on a system of about 5,400 miles until issues with durability started to occur. A national study questioned the effectiveness of RPM in reducing crashes (5) and at least one state conducted a survey to evaluate the durability of these markers (6). These concerns resulted in a study to evaluate the effectiveness and durability of snowplowable RPM installed in Kentucky (7). The study concluded that continued use of the currently approved snowplowable raised pavement marker can be justified if the castings are properly installed on new pavements with a...
commitment that the adjacent pavement will be maintained. The study recommended an
evaluation of: a) alternative snowplowable marker designs, b) paint and tape marketed as
having the capability of providing delineation during wet conditions, and c) use of centerline
and edge line rumble stripes.

The investigation and evaluation of alternative lane delineation materials have been the
subject of research in Kentucky for many years. A study conducted in 1981 involved a survey of
lane delineation methods used across the country with information obtained from 46 states (8).
Information was included related to the use of raised pavement markers, pavement tape,
thermoplastic markings, and paint and beads.

A series of reports were conducted from 1975 through 1991 dealing with an evaluation
of pavement markings materials with an emphasis on long-term durable lane delineation
materials (9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20). The reports included an evaluation of
paint-stripe beads, thermoplastics (such as extruded and epoxy), various types of pavement
tapes, and various types of paint (such as polyester and epoxy). Most of these studies dealt
with the durability of the various materials as opposed to their effectiveness during wet-
nighttime conditions. The durability of the materials on various pavement types were
evaluated with their cost effectiveness analyzed.

Rumble stripes (both centerline and edge line) have been installed in Kentucky for the
past few years. The first evaluation was conducted in 2010 (21). The evaluation supported
continued use of rumble stripes as a method to decrease lane departure crashes and provide
improved wet-nighttime delineation. A more recent evaluation of the first large-scale
installations of rumble stripes found positive results for rumble stripes in reducing lane
departure crashes.

There have been a few isolated installations in Kentucky of paint and tape which are
marketed as providing wet-nighttime delineation. There has been no formal evaluation of
these small installations. The installations were surfaced applied with resulting snowplow
damage.

The most recent evaluation of long-term pavement marking performance showed that
typical paint striped lines can produce passing retroreflectivity levels after two years (22).
Minimum retroreflectivity levels were recommended but the evaluation did not involve an
evaluation during wet conditions.
There has been substantial research across the nation in the past dealing with alternative materials and procedures which might provide effective lane delineation during wet-nighttime conditions. Following is a summary of some of the recent research in this area. The focus of this review was on various types of paints and tapes. A comparison with raised pavement markers was included in some of the literature.

A discussion of products and practices for pavement markings was the subject of a webinar (23). Products and procedures used in Kansas were discussed. Bead packages included blended beads for single drop, double drop, and high performance beads. Rumble stripes were reviewed as a method of providing increased delineation. Cost comparisons for durable markings included: high build water-borne paint (12 cents per foot with 18-month life); hybrid or multi-component (45 cents per foot with 48 months or more life); methy-methacrylate (MMA) profiled (three dollars per foot with 72 months or more life); and grooved patterned cold plastic (five dollars per foot with 72 months or more life).

An all-weather pavement marking system for work zones was described in another study (24). The marking system used 3M All-Weather Paint which combines high-build waterborne paint and glass beads with optical elements made of a ceramic core surrounded by high-refractive index beads. This material was found to be significantly more reflective than standard paint when correctly installed. Variations in retroreflectivity readings suggested that paint application methods may not have been consistent. In most cases, the evaluation found that motorists maintained safer lane placements when traveling in lanes marked with the all-weather paint.

A two-year, long-line test deck of a variety of wet-reflective pavement marking materials and treatments under wet night conditions was evaluated in an Iowa study (25). The evaluation parameters included durability and retroreflectivity (both dry and wet). The primary source of pavement marking damage was found to be from winter maintenance operations. Grooved markings performed better than surface applied markings. Surface-applied sections lost 20 percent more wet-reflectivity than grooved sections. The products evaluated included: mult-polymer, hybridized epoxy, urethane epoxy; high-build double drop beads; epoxy; all-weather paint; methy-methacrylate; all-weather tape; and epoflex. The cost for a four-inch line varied from $0.19 for a double drop bead to $1.57 for all-weather tape.

A patent for a preformed thermoplastic pavement marking material was proposed to provide improved performance in wet night conditions (26). The material used embedded large
retroreflective beads which resulted in a minimum retroreflectance of 100 millicandelas (mcd) in standard conditions of wetness.

One study involved an evaluation of rumble stripes in providing long term retroreflectivity (27). Rumble stripes were shown to offer better nighttime visibility than the standard painted line. In addition to the effectiveness of the rumble’s auditory and vibratory warning in reducing crashes caused by lane departures, rumble stripes were found to enhance the visibility of the roadway under night and wet-night conditions. Snowplow wear was noted as the primary cause of bead loss and retroreflectivity degradation followed by tire contact. Rumble stripes provided improved durability of the pavement marking relating to damage by winter snow plowing operations.

Use of a “recess triple drop” marking system has been used in New York to provide a more visible and durable marking in all lighting and weather conditions (28). The material uses ceramic elements mixed with various sized glass beads and applied onto a recessed epoxy base. The material is placed in a groove a tenth of an inch deep which protects the markings from plow damage. Epoxy is sprayed into the groove at a thickness of 20 mils with wet-reflective ceramic elements then placed followed by large glass beads and small glass beads.

The Florida Department of Transportation established a wet-weather pavement marking demonstration project with goals to gather performance data, evaluate various wet-weather marking systems, and develop a measurement protocol for measuring retroreflectivity under continuous wetting conditions (29). Guidelines were developed for a measurement protocol for measuring the retroreflective performance of pavement markings systems under continuous wetting conditions based on a wetting rate of approximately two inches per hour.

Three prototype paint marking systems employing high refractive index dual-optics drop-on elements were evaluated at night during dry, wet-recovery and rain conditions (30). The systems included a dual-optic system and two commercially available marking systems (glass beads-on-paint and wet-reflective removable tape). In wet recovery, all three prototype marking systems and the wet-reflective type sustained 60 to 80 percent of their dry average detection distance and, in rain, they sustained 50 to 70 percent of their dry average detection distances. In contrast, the average wet-recovery and rain detection distances for the conventional glass beads-on-paint system dropped to 28 to 17 percent of the dry detection distance. Participants failed to detect the conventional glass beads-on-paint system in nearly half of the observations in the rain condition.
The Virginia Department of Transportation prepared an overview of work in the area of durable, retroreflective pavement markings and markers to increase visibility for drivers in wet, night conditions (31). It was noted that pavement markings reduce crashes at night on dry pavement but not at night on wet pavement (due to reduced retroreflectivity). It was also noted that marking retroreflectivity under wet pavement conditions averaged only 46 percent of values under dry pavement conditions (so a dry value of 326 mcd would be necessary to achieve a wet value of 150 mcd).

Evaluations using test subjects driving in controlled test sections have been used to evaluate various marking materials (32). The results of one evaluation showed that wet retroreflective tape provided the longest visibility distance, followed by profile thermoplastic and large glass beads, with standard paint providing the shortest visibility distance. The level of retroflectivity provided by the materials tested did not provide adequate visibility distance for a sedan with a two-second visibility time at speeds greater than 45 mph.

Another study evaluated the performance of wet-night pavement markings and driver understanding of and preferences for contrast pavement markings (33). The use of contrast markings is increasing across the country with preference of black borders on the outside of the marking. Wet-night detection distances for raised pavement markers far exceed detection distances for other markings. The recommendation was made to continue use of raised pavement markers as the wet-night delineation treatment in Texas. The cost of installing and maintaining raised pavement markers was about $75 per mile at an 80-foot spacing compared to $475 per mile for thermoplastic markings and $3,300 per mile for the best wet-performing pavement markings. Also, wet retroreflectivity measurements made in accordance with ASTM specifications were found to be unreliable with weak correlation to performance so it was recommended to avoid specifying marking performance based on ASTM wet retroreflective standard measurement procedures.

The materials evaluated in another study included waterborne paints, thermoplastics, tapes, and exotic materials along with the wet-night visibility of rumble stripes and wider lines (34). For average rainfall rate, rumble stripes increased the detection distance about 38 percent. For heavy rainfall, the increase was about 13 percent. Increasing the stripe width from four to six inches provided about a 30 percent increase in detection distance during wet-night conditions. The wet-night detection distance of raised pavement markers was over 550 feet which was over 200 feet longer than the longest detection distance for any other marking tested. The second longest detection distance was for tapes. The benefit of bigger beads was particularly noticeable during heavier rainfall events. For thermoplastic markings, double drop with large high refractive index beads provided increased wet-nighttime detection distances for
all rainfall rates. Considering exotic materials, the polyuria with bead clusters performed well during low and medium rainfall rates but performance dropped during heavy rainfall. The splattered MMA with big beads performed well. It was noted that wet retroreflectivity measurements cannot be predicted based on the dry retroreflectivity measurements.

A study evaluated the visibility of six pavement marking materials under a simulated rain system using information from participants (35). There was a high degree of correlation between measured and calculated values of retroreflectivity. Significant differences were found in the time required for the visual performance to recover from rain for paint and bead products versus profiled thermoplastic and wet retroreflective tape.

The nighttime visibility of large beads and tapes was evaluated under dry and wet conditions (36). Data were obtained both from participants driving a test section along with measurements using retroreflectometers. Paint with large beads was comparable to tape with high-index beads during wet conditions. In terms of end-detection distances, the patterned tape with mixed high-index beads performed best under all weather conditions.

A survey was conducted by the Maine DOT to determine less noisy alternatives for rumble strips (37). The replies included methods to provide wet nighttime delineation. The alternatives included: raised or recessed pavement markers; profile thermoplastic; milled centerline and edge line rumble stripes; 3M product Audible All-Weather Thermoplastic; street lighting; Rainline product; and built-up pavement markings.

A recent study evaluated the durability of several types of pavement markings at an on-road installation (38). A human factors experiment in natural rain conditions was performed to establish the visibility needs of the driver. The data supported the use of 150 mcd as the minimum retroreflectivity to provide adequate visibility for drivers in wet night conditions. Six types of pavement markings were tested with three installation methods (surface, groove, and rumble strip) for a total of 12 different conditions. The wet-reflective tape and two types of high-build paint outperformed the other markings (thermoplastic, MMA, and polyuria). Markings in rumble strips were detected at significantly longer distances than markings in grooves and on the surface. While all the markings lost reflectivity after the first winter, markings in grooves sustained less damage than the surface applied. After 23 months all the pavement markings had dropped below 150 mcd during wet conditions with the wet-reflective tape closest to that value (about 137 mcd). Several other types had a level over 84 mcd which may provide a benefit over standard paint.
An evaluation of a mobile retroreflectometer unit (MRU) found no statistically significant bias indicating that the device produces similar retroreflectance measurements as the handheld retroreflectometer (39). Also, similar results were found when two different MRUs were used on the same pavement marking section.

A research study determined whether a correlation between pavement marking retroreflectivity and safety can be established (40). The findings provided support to the positive safety effects of maintaining retroreflectivity of pavement markings.

A report from North Dakota found that roads are generally safer after the installation of rumble stripes (41). A reduction in all crashes and crash severity, in terms of the most serious fatal crashes, was found in comparing crash rates before and after installations. It was noted that the contour of the rumble strip is better at draining water and improves visibility at night with adverse weather conditions.

The use of rumble stripes has been increasing across the nation. A recent internet survey was conducted relative to the use of rumble stripes. There was general agreement that the visibility of the paint line was increased through the use of a rumble stripe. While the extent of the increase has not been quantified, observations are consistent showing increased visibility during wet, nighttime conditions. No significant maintenance issues were noted by the survey respondents.

A study from Michigan found that centerline rumble strips improved lane positioning and decreased centerline encroachments (42). Adding shoulder rumble strips improved lane positioning and decreased edge line encroachments.

### 4.0 ALTERNATIVE PAVEMENT MARKING SYSTEMS

Pavement marking systems identified which have the potential to provide wet-nighttime delineation could be placed into the following general categories.

a. raised pavement markers,
b. thermoplastic material,
c. wet-reflective paint,
d. wet-reflective tape, and
e. rumble stripes.
Following is a discussion of the past use of these systems in Kentucky and the potential for use in the future to provide wet-nighttime delineation.

4.1 Raised Pavement Markers

Raised pavement markers (RPM) have provided the most effective method of providing wet-nighttime delineation. RPMs provide a longer detection distance than the alternative marking systems. The most recent evaluation of RPM installations in Kentucky recommended their continued use with the requirement that the castings must be properly installed on new pavements with a commitment that the adjacent pavement will be maintained (6). Also, the lenses must be replaced on a regular (approximate three-year cycle) basis to maintain their effectiveness. The stability of the casting must be inspected as part of the lenses replacement process with any castings which are loose or have surrounding pavement failure removed.

Due to durability issues with the standard steel casting RPM, the study (6) also recommended an evaluation of alternative snowplowable marker designs. Another University of Kentucky study has included an evaluation of the use of a recessed marker design using the same lenses which is placed in the standard casting. Also, at least one other manufacturer has developed an alternative design for the standard steel casting RPM.

Current policy is to use RPM on interstates, parkways, and other four-lane highways. In the past they were also installed on two-lane roadways but are no longer being used when two lane roads are resurfaced. Rural, two-lane roadways represent the highest percentage of mileage in the state and have the highest fatal crash rate (43). If RPM are not used, an alternative method of providing wet-nighttime delineation on two-lane roads must be developed.

4.2 Thermoplastic Material

Thermoplastic markings have been used for many years in Kentucky for lane delineation as well as other pavement markings such as stop bars and crosswalks. The first formal evaluation in Kentucky was in 1976 with recommendations made concerning where this marking material should be used (10). This type of marking material has been used most often on high volume roads with asphalt pavement. This material is substantially thicker than a typical paint line so it provides a potential for wet nighttime delineation. However, the material is subject to snowplow damage given Kentucky’s current policy of using steel snowplow blades with a “bare pavement” policy.
A test section of ribbon thermoplastic was installed in Washington County on KY 555 in August 2010. The test section was installed as an edge line (over a rumble strip) on a two lane road (about 0.8 mile in length) with asphalt pavement. Very high retroreflectivity initial measurements were found (over 500 mcd on a dry pavement and over 200 mcd on a wet pavement). Evidence of snowplow contact to the top of the thermoplastic material was noted but, since beads were placed through the material, retroreflectivity measurements of over 700 mcd were obtained in October 2011 and again in October 2012 and April 2013. Nighttime observations confirmed the high retroreflectivity measurements. None of the material was missing after close to three years and three winter seasons.

A test installation of extruded thermoplastic (placed in a groove) is being placed in Warren County on KY 234. The groove depth for the thermoplastic is 120 mils.

4.3 Wet-reflective Paint

Test installations of wet-reflective paint (placed in a groove) are being placed at the following locations:

- Franklin County on KY 420
- Kenton County on KY 1501
- Nelson County on US 31W

The groove depth for the paint is 50 mils. The installation consists of placement of waterborne paint followed by the application of wet reflective beads. The waterborne paint is applied at a minimum rate of 25 gallons/mile. The wet-reflective beads are mechanically applied to the wet paint directly behind the paint spray guns.

4.4 Wet-reflective Tape

A test installation of wet-reflective tape (placed in a groove) is being placed in Franklin County on US 127. The groove depth for the tape is 80 mils. The tape is applied at a minimum thickness of 60 mils.

Another test installation of inlaid wet-reflective tape has been scheduled in Franklin County on KY 420. A very small installation of this type of tape was surface applied at an isolated location in Boyle County but sustained significant snowplow damage.
4.5 Rumble Stripes

Rumble stripe installations include milled edge line or centerline markings with the edge and centerline paint lines placed over the milled rumble strip. The initial evaluation of rumble stripes supported continued use (21).

An initial evaluation of crash data found that the rumble stripe installations have resulted in a reduction in lane departure and wet-nighttime crashes. An analysis of crash data found a 17 percent reduction in wet-nighttime crashes, a 17 percent reduction in lane departure crashes, and a 10 percent reduction in total crashes after installation of rumble stripes on rural, two-lane roads. The rumble stripes were used as an edge line, centerline, or both. Nighttime observations during wet conditions have shown an increased visibility of rumble stripes compared to typical traffic paint. This observation is supported by information found in the literature review.

5.0 CONCLUSIONS

Following is a summary of conclusions for future procedures and materials which should be considered to provide effective lane delineation during wet-nighttime conditions.

- Snowplowable raised pavement markers should continue to be used on interstates, parkways, and other four-lane highways when they are resurfaced. The installation process must ensure the markers are not placed on or adjacent to the pavement joint.

- Lenses in the steel casting raised pavement markers should be replaced on a three-year cycle. The condition of the castings should be inspected as part of this process.

- The pavement condition adjacent to the raised pavement marker castings should be monitored to ensure there is no failure adjacent to the casting.

- Evaluation of the use of a recessed pavement marker (as an alternative to the steel casting marker) should continue.
• Rumble stripes (painting edge line and centerline markings across a milled rumble strip) should be routinely used on resurfacing projects on rural, two-lane roads. Guidelines have been developed for the use of an edge line and/or centerline rumble stripe related to the pavement width.

• Evaluation of the grooved and inlay installations of the wet-reflective paint, tape, and thermoplastic material should continue.

• The effectiveness of surface-applied pavement marking materials which have the potential to provide wet-nighttime delineation is inhibited due to snowplow damage. Current research for an alternative to the current “bare pavement” policy (which involves use of steel snowplow blades with full weight) should be continued. Alternatives include use of an alternative snowplow blade or a method of reducing the weight of the plow blade applied to the pavement.
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