Prepared by Misty A. Boos, January 2009

KEY SEARCH TERMS:

- Retroreflectivity
- Durability
- Wet Weather
- Night Visibility
- Road Markings

Research Synthesis Bibliography No. 20

Research Synthesis Bibliographies (RSBs) are distillations of relevant transportation research on current topics of interest to researchers, engineers, and policy/decision makers. Sources cited are available for loan (or available through Interlibrary Loan) to VDOT employees through the VDOT Research Library.
Research Explores Ways to Meet Driver Visibility Needs in Wet, Night Conditions

Increasing retroreflectivity of markings during rainy, foggy, nighttime conditions is a major challenge. Research has shown that pavement markings reduce crashes at night on dry pavement, but not at night on wet pavement. (Migletz, 2002 pg. 6)

Because of the need to improve visibility for drivers under adverse conditions, recent research (2000 to the present) has been targeted toward understanding visibility needs and developing minimum retroreflectivity specifications for different driver groups under different environmental conditions. Research on this topic has been compiled in this RSB in section II: “Wet Night Visibility of Pavement Markings.”

Increased retroreflectivity performance in wet, night conditions may help to reduce fatalities, but ensuring and defining this improved performance includes a particular set of challenges. For example, “Pavement marking retroreflectivity under wet pavement conditions averaged only 46% of the comparable values under dry pavement conditions. For example, to achieve a wet pavement retroreflectivity of 150 mcd/m²/ lux, the marking would need a dry-pavement retroreflectivity of 326 mcd/m²/ lux.” (Migletz, 2002 pg. 2)

Challenges to improving retroreflectivity performance mentioned in recent research include:

- Type of material and installation methods.
- Service life, durability and cost of durable materials.
- Damage to materials by forces such as weather and traffic wear.
- Setting minimum reflectivity standards (as cited in the MUTCD 2003 and/or by state DOTs).
- Developing strategies and tools to measure retroreflectivity.
- Marking and marker installation issues including increasing shortages of skilled workers for installation and maintenance.
- Location of installation, climate and traffic load on roadway.
- Funding and standards for maintenance.
- Many new technologies entering the market, each requiring evaluation.
- Environmental regulations.
- Product acceptance and approval.
- Driver needs (including differing needs based on driver age and time of day).
- Vehicle type and the visibility concerns of trucks vs. cars.

The durability and service life of retroreflective materials is of particular concern because the service life of some pavement markings and markers can be very short (as little as 6 months in some cases). When these markings fail or their reflectivity is reduced drivers experience difficulty seeing the road. (Migletz, 2002)

The following organizations have explored the durability or service-life of pavement markers and markings. Their work can be found in section I: “Durability of Retroreflective Pavement Markings, Markers”

- Texas Transportation Institute (TTI)
- Virginia Transportation Research Council (VTRC)
- Federal Highway Administration (FHWA)
- New Jersey DOT
- Alabama DOT
The following organizations have proposed research into retroreflectivity or wet, nighttime driving conditions. Their proposals can be found in this RSB Section III: “Research in Progress.”

- Oregon DOT
- Florida DOT
- Georgia DOT
- Indiana DOT
- American Society of Civil Engineers
- ARRB Group Ltd.

- Oregon State University
- Iowa State University
- Mississippi State University
- North Dakota DOT
- Pennsylvania DOT

When durable, retroreflective pavement markings are properly selected for a site and installed and maintained correctly they can help drivers navigate in wet night conditions and they have the potential to decrease traffic fatalities. Research, listed in the following pages, provides an overview of current work, but much exploration remains to be done on this complex issue.

--- Misty A. Boos

**DATABASES SEARCHED FOR THIS RSB**

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**OVERVIEW**

Research Synthesis Bibliographies (RSBs) are selected lists of resources on current topics of interest to VDOT employees or divisions. When available, links to online documents are provided.

RSBs are “selective listings,” organized and distilled from the larger universe of research materials to save the researcher’s time. Selection criteria used by library staff include authority, relevance, and timeliness.

**GETTING RESOURCES LISTED HERE**

Full text copies of most resources listed in this document are available in the VDOT Research Library’s collections, or through Interlibrary loan, through the Library. In many cases, the Library owns both virtual and hard copies of documents, as well as formats such as CD-ROM.

Library staff is available Monday-Friday 8:00-5:00. Please contact us if you have a reference question, a question about our lending policies, or need any other kind of help.

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I. DURABILITY OF RETROREFLECTIVE PAVEMENT MARKINGS, MARKERS

Long-Term Pavement Marking Practices
DATE: 2002
ABSTRACT: This synthesis report will be of interest to local and state transportation agencies as well as to the pavement marking industry that works with them in long-term pavement marking practices. This report documents the current and best practices for managing pavement marking systems, identifies future needs, and addresses driver needs and methods of communicating information to drivers, selection criteria (e.g., reflectivity, pavement service life, wet weather performance), materials (e.g., color, durability, cost), specifications, construction practices, and inventory management systems. It also explores several challenges facing agencies, including funding, nighttime visibility in rain and fog, quality control after installation, and the shortage of quality labor, and discusses new technologies, methods of performance measurement, and environmental constraints. This report of the Transportation Research Board contains information derived from survey responses from 61 state, province and territory, county, and city transportation agencies and private companies in the United States and Canada to document long-term pavement marking practices and research, and discusses the many different practices among agencies due to variations in structure, policies, and climate.

Evaluation of the Performance of Permanent Pavement Markings And Retro Reflectors In Snowplowable Raised Pavement Markers
DATE: 2002
CITATION: Parker, Neville A. University Transportation Research Center. Region II., New Jersey. Dept. of Transportation. and United States. Federal Highway Administration, University Transportation Research Center, Region II.
ABSTRACT: In anticipation of federal retroreflectivity standards for pavement markings, the New Jersey Department of Transportation (NJDOT) undertook to evaluate their three-year fixed schedule restriping strategy, to see if it is consistent with the actual service life of the pavement markings. One of the primary tasks was to develop a threshold value of retroreflectivity level below which a pavement marking will no longer be considered "bright enough" to be useful for motorist nighttime guidance. The results suggested that the threshold value of acceptable versus unacceptable level of retroreflectivity appeared to be between 80 and 130 mcd/m2/lux, for New Jersey drivers of age less than 55 years, and between 120-165 mcd/m2/lux for drivers older than 55. This result is consistent with conclusions reached by other investigators on similar research, with results generally ranging between 70-170 mcd/m2/lux. The analysis further suggests that, concentrating resources on restriping New Jersey pavement markings with retroreflectivity below 130 mcd/m2/lux would achieve a greater relative increase in driver satisfaction than restriping pavement markings with retroreflectivity above 130 mcd/m2/lux. The Interim Visibility Indices (IVI) were developed for each age group based on pavement marking type, for use by NJDOT in determining and prioritizing needs and qualification of related resources required, based on the threshold between acceptable and unacceptable retroreflectivity,
when developing the new pavement marking management system. This will also allow for
cost benefit/life cycle analysis for different pavement marking materials.
ACCESS: Please see the VDOT Research Library

**Cost Effective Performance Driven Improved Safety Benefits From Horizontal Painted Pavement Marking Systems**
ABSTRACT: Horizontal painted pavement marking materials are applied to road surfaces to provide safe guidance for the traveling road user public. These markings need to function both day and night, wet and dry, to provide safe guidance and clear signals at a consistent level while presenting a preview of the forward road geometry. Such delineation systems may create a potential hazard if the differential friction between the marking and the pavement exists, particularly for cyclists and motorcyclists. Potters Industries, has taken the initiative in developing safer systems and generating data to assist the pavement marking industry. Requirements for Performance Based Contracts for pavement markings are fast approaching, with little data to assist the specifying engineer on realistic intervention levels that can deliver safe performance outcomes. These 'safe outcomes' should include minimum levels in dry night visibility, wet night visibility and skid resistance for both transverse and longitudinal pavement markings, throughout the life of these markings. To provide the anticipated levels of skid resistance, usually requires a surface application of angular particles. These angular particles may create shadows over the surface applied glass beads and render the line invisible during night conditions. The challenge has been to find a balance between angular and spherical surface applied particles, in size, quality, quantity, ratio and method of application, that can provide durable cost effective horizontal pavement markings with excellent dry night delineation, excellent wet night delineation and a high level of skid resistance. Full conference proceedings available on CD-ROM.
ACCESS: Please see the VDOT Research Library

**Evaluation of Profiled Pavement Markings**
DATE: 2003
ABSTRACT: This study evaluated flat thermoplastic markings (FTM) and profiled pavement markings (PPM) installed on highways maintained by the Alabama Department of Transportation. The primary objectives of this evaluation were to compare service life, life-cycle costs, crash rates, and wet-night visibility (measured by wet retroreflectivity) of the two marking types. Nighttime dry and wet retroreflectivity of 16 one-mile segments of FTM and 21 one-mile segments of PPM were measured using a mobile retroreflectometer. The average dry retroreflectivity of new FTM and PPM tested by this study were 320 and 242 mcd/m²/lux, respectively. In addition, both FTM and PPM were found to lose dry retroreflectivity at similar rates with respect to cumulative traffic passes. As a result, under similar average daily traffic levels, FTM consistently provides a higher dry retroreflectivity than PPM of the same age. On average, FTM was found to last six or more months longer than PPM. The average wet retroreflectivity of PPM at the end of its service life was found to be as high as the average wet retroreflectivity of FTM at the beginning of its life. However, crash data analysis did not indicate that the higher retroreflectivity of PPM resulted in a lower crash rate than FTM. The life cycle cost analysis showed that for a five-year marking service life and an eight year life cycle, the cost per mile of marking was $1,355 for FTM and $4,240 for PPM. Overall, the study found that economics, marking service life, and crash data do not justify widespread use of PPM in preference to FTM.
Defining Relationship Between Initial and One-Year Pavement Marking Retroreflectivity
DATE: 2006
ABSTRACT: This paper investigates the change in retained retroreflectivity of waterborne paint and spray thermoplastic pavement markings, before and after winter maintenance. The research hypothesis is that if the pertinent initial conditions are known, such as fall retroreflectivity, marking material, and line type, it is possible to predict future performance for a given variable such as annual winter maintenance. Individual pairs of fall and spring retroreflectivity readings, from hundreds of separate statewide, sites are analyzed to show, among other things, that fall retroreflectivity and product type are predictors of spring retroreflectivity. In general, as fall retroreflectivity increases, the percent retroreflectivity retained by spring decreases in a predictable fashion for both waterborne and spray thermoplastic pavement markings.
ACCESS: Please see the VDOT Research Library

Evaluation of Snowplowable Raised Pavement Marker Failures
DATE: 2007
ABSTRACT: A commonly used method to delineate lane lines on Virginia's highway pavements is a combination of reflective tape and snowplowable raised pavement markers (SRPMs). The SRPM system consists of a reflective lens epoxied into a plow deflector. The deflector is typically an H-shaped protective steel or cast-iron casting that consists of a pair of parallel keels and a connecting web. The entire system weighs approximately 6 pounds. While this arrangement is thought to improve the visibility of lane lines during darkness and inclement weather, there are questions as to whether the SRPMs can become damaged or detached from the pavement after prolonged exposure to traffic and snowplows. In Virginia, there is no formalized method or schedule for routinely inspecting these markers. They are often examined only when repaving or restriping is scheduled. In April 2006, a SRPM fragment went through the windshield of a van traveling on I-95 in Prince William County, striking a passenger. In response to this incident, a statewide study was initiated to determine if there were any potential problems with SRPMs becoming damaged or detached on Virginia's interstates. Casting condition, reflector condition, epoxy condition, and installation adequacy were inspected on 78 1-mile segments of interstate pavement containing SRPMs. The focus of the study was on sections of pavement that were at least 5 years old and carried current year traffic volumes greater than 15,000 vehicles per day. The study found that nearly 8 percent of all SRPM castings inspected were either missing or damaged. Approximately 35 percent of reflectors inspected were either missing or damaged. An analysis of risk factors showed that epoxy condition, total traffic since installation, and installation adequacy were the most significant factors in determining the condition of the marker casting and reflector. Total accumulated snowfall since installation, pavement type, pavement condition, and pavement age were also found potentially to play a role in SRPM failures. Total traffic since installation was found to offer the best ability to predict casting and reflector failure, and two models were developed to define potential SRPM inspection thresholds. The study recommends increased training for installers and inspectors and the development of a regular program for inspection of the marker casting and reflector. In addition, this study recommends that VDOT develop a SRPM installation protocol such that the raised markers are placed only in areas where they will be most effective.
ACCESS: Please see the VDOT Research Library

Durability and Retro-Reflectivity Of Pavement Markings (Synthesis Study)
DATE: 2008
CITATION: Jiang Yi, Purdue University, Indiana Dept of Transp JHRP, USA and Federal 3

ABSTRACT: Waterborne paints are used to paint pavement markings (edgelines and centerlines) to provide guidance for motorists. The painted markings need to be repainted periodically as their retro-reflectivity deteriorates. The Indiana Department of Transportation (INDOT) repaints pavement markings at least annually. INDOT engineers would like to determine the feasibility of extending the time intervals of repainting pavement markings on at least some types of roadways. The purpose of this synthesis study is to accomplish the following: (1) to locate and assemble documented information on pavement marking durability; (2) to learn what criteria have been used in other states in measuring retro-reflectivity and scheduling pavement marking painting; (3) to determine the necessity of conducting full scale study on INDOT pavement markings; (4) to identify the type and cost of equipment required for retro-reflectivity measurements and conditions of operation of the equipment; (5) to organize, evaluate, and document the useful information that is acquired; and (6) to provide recommendations based on the evaluated information. This report presents the findings of the synthesis study on various pavement marking materials. It was found in this study that many state highway agencies have evaluated several types of pavement marking materials. The evaluation results include performance, cost, service life, and retro-reflectivity measuring equipment of marking materials. However, the results could vary from different states. The information gathered through this study will provide INDOT engineers the state-of practice of pavement marking materials in this country.

ACCESS: http://www.swan.ac.uk/german/bcla/clcwebjournal/docs.lib.purdue.edu/cgi/viewcontent?article=1704&context=jtrp

Evaluation of Inlaid Durable Pavement Markings in an Oregon Snow Zone

DATE: 2006
CITATION: Lynde, McGregor. Oregon Department of Transportation; Federal Highway Administration, 63p.

ABSTRACT: The Oregon Department of Transportation (ODOT) evaluated the use of inlaid durable pavement markings within a snow zone. Three different durable pavement marking products were installed and evaluated: Dura-Stripe®, a methyl methacrylate; Permaline®, an alkyd based thermoplastic; and, 3M™ Stamark™ Series 380 I Tape, a preformed tape. Each product was applied, at various thicknesses, into a 4 in. (102 mm) wide slot ground to various depths. The slot depths were: 250, 180 and 125 mil (6.35, 4.57 and 3.18 mm). The material thickness was varied to achieve a recess from the surface of the pavement of 30 and 60 mil (0.76 and 1.52 mm) below the surface and 10 mil (0.25 mm) above the surface of the pavement. Some sections of the test deck were installed using ODOT’s existing specification of a 250 mil (6.35 mm) deep slot completely filled with material and top coated with reflective beads. After each winter maintenance season the test sections were evaluated based on durability and retroreflectivity. This report summarizes the performance of the test sections after two years in-service. Recommendations about the future use of inlaid durable pavement markings in snow zones are made, including slot and material depth, and material type. A proposed standard for inlaid durable pavement markings is also presented.


Durability of Preformed Thermoplastic Pavement Markings for Horizontal Signing Applications

DATE: 2006
CITATION: Chrysler, Susan T., Steven D. Schrock and Timothy J. Gates. Texas Transportation Institute; Texas Department of Transportation; Federal Highway Administration, 152p.

ABSTRACT: The results of two-year durability tests of preformed thermoplastic pavement marking materials are reported. A survey of material manufacturers is also presented. Pavement marking materials in the form of transverse lines, arrowheads, and sections of the letter S were installed at test decks on three Texas roadways. Small square sections of
colored pavement marking materials were also tested for some of the manufacturers. Manufacturers' representatives performed the installations. Three types of pavement surface were tested: concrete, asphalt, and seal coat. Retroreflectivity and color measurements of the materials were made at the time of installation, after one year, and after two years. Thickness of the material was measured prior to installation and at the same time intervals using video microscopy of samples chiseled from the roadway.


Effective Pavement Marking Materials And Applications For Portland Cement Concrete Roadways
DATE: 2003
ABSTRACT: This report describes the tasks of a study conducted to identify effective pavement marking materials and application procedures on portland cement concrete (PCC) roadways in Texas. The researchers reviewed relevant literature, reviewed data from the National Transportation Product Evaluation Program (NTPEP), surveyed state departments of transportation, surveyed material manufacturers, and analyzed cost-effectiveness of various materials. Based on findings from the research tasks, the researchers generated a number of recommendations for pavement markings on PCC roadways in Texas, which include: use epoxy materials for long-term applications under the majority of traffic conditions; use preformed tape for long-term applications under very heavy traffic; and use Texas Department of Transportation specification thermoplastic only for short-term applications with low to medium traffic.
Research Project Title: Evaluation of Pavement Marking Effectiveness.

Determining The Effectiveness of Pavement Marking Materials
DATE: 2001
ABSTRACT: The purpose of this research was to determine the safety, motorist opinion, and cost-effectiveness of pavement marking materials used by the Virginia Department of Transportation and to develop guidelines, where possible, as to when each type of material should be used. Interstate and primary road segments that had been remarked with a different type of pavement marking material were identified to perform a before-and-after accident analysis. When possible, segments that were remarked using the same pavement marking material were included to provide comparison sections. The number of sites and accident count data were insufficient to support a finding that the use of a particular pavement marking material reduces the number of target accidents. The results of a motorist survey indicated that the participating drivers were more satisfied with pavement markings with higher retroreflectivity values than those with lower values. Participating drivers over the age of 65 were generally less satisfied with the brightness of the pavement markings than were participating drivers under the age of 65. Using a large contract for paint was the most cost-effective for two-lane roads under most volume conditions and four- and six-lane low-volume roads. Using polyurea and a large contract for paint were the most cost-effective for high-volume two- and four-lane roads. Polyurea and waffle tape were the more cost-effective durable markings for high-volume six lane roads. Changes in the use of pavement markings were recommended. Specifically, the Virginia Department of Transportation should (1) consider increasing the use of large paint contracts and minimizing its use of small paint contracts when possible; (2) consider a performance-based specification for durable markings; (3) continue consideration of a holistic approach for pavement management and markings; and (4) re-evaluate its pavement marking policy and include the recommendations of this study.
ACCESS: http://www.virginiadot.org/vtrc/main/online%5Freports/pdf/01-r9.pdf
Evaluation of Traffic Markings in Cold Regions

DATE: 1998
ABSTRACT: This paper summarizes a research project that evaluated the performance of traffic marking materials used in Alaska and other northwestern states. This study was conducted by reviewing existing reports, past studies, and information databases; conducting a field survey that rated existing traffic marking; conducting field measurements of retroflectivity of traffic markings using a reflectometer; and conducting a subjective opinion survey about the performance of traffic markings used in cold regions. Results summarized in this paper include impacts of traffic marking patterns on driver behavior, minimum reflectivity requirements, a general evaluation of traffic marking materials, field survey, reflectivity performance, subjective survey evaluation, and final conclusions. The traffic marking material types evaluated in this study included traffic paint, thermoplastics, preformed tapes, and methyl methacrylate. These traffic marking materials have been applied in Alaska and some northern states.
ACCESS: Please see the VDOT Research Library


DATE: 2002
ACCESS: Please see the VDOT Research Library

The Way To Safety

DATE: 2001
CITATION: Kerschner, E. World Highways/Routes du Monde, Route One Publishing Limited, 10, 8, p. 68-69.
ABSTRACT: Studies show that the number of traffic accidents increases at night, especially in bad weather. Profiled marking improves retroreflection at night and during rainfall. In profiled marking, reflective glass beads on top and on the sloped side of the individual profiles reflect the beam of the headlights. Because the driver sees the marking at a flat angle, the individual profiles go unnoticed and a continuous line stays visible when it rains. Profiled markings also work as an audio warning system when passed by a vehicle. This alerts drivers as they cross the lines in the dark. A low noise version of profiled marking called agglomerates is available for residential areas. Another type of rain safety marking based on methacrylate is the spray-applied version called cold spray plastic, which uses large-size reflective glass beads. Cold plastic markings offer increased safety, outstanding durability and are environmentally-friendly.
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II. WET, NIGHT VISIBILITY OF PAVEMENT MARKINGS

Evaluation of Wet-Weather Pavement Markings: First Year Report

DATE: 2005
CITATION: Carlson, Paul J., Jeffrey D. Miles, Michael P. Pratt and Adam M. Pike. Texas Transportation Institute; Texas Department of Transportation; Federal Highway Administration, 115p.
ABSTRACT: This report details the first year of a two-year project. During the first year the emphasis was on determining the wet-night visibility of various pavement marking systems under a variety of realistic rainfall levels. The researchers performed a literature review. They analyzed 20 years of Texas rainfall data to determine the most appropriate rainfall levels to use as design criteria for a rain tunnel. Using a low, medium, and high rainfall rate (0.28, 0.52, and 0.87 in. per hour, respectively), a 1600 ft long rain tunnel
was designed and built at Texas A&M University's Riverside Campus. Experimental subjects drove through the rain tunnel and looked for pavement markings simulating skip lines. The researchers rotated pavement marking samples at different locations before each trial. The detection distance was recorded when the subject located the pavement marking sample. The data were analyzed in four main sections: waterborne paints, thermoplastics, tapes, and exotic materials. The analysis also included investigations into the **wet-night visibility** of rumble stripes, as well as wider lines. The measured dry and wet retroreflectivity measurements were analyzed, and the predictive capabilities of the wet retroreflectivity measurements were evaluated with respect to the wet-night detection distance of the markings. During year two the researchers will supplement the detection distance data with additional data from a second round of wet-night visibility experiments. The researchers will also consider **durability and cost** information before finalizing the research. The researchers will also develop and implement research activities that can be used to develop application recommendations for contrast pavement marking materials based on visibility performance, durability, and cost.


**Evaluation of Wet-Weather and Contrast Pavement Marking Applications: Final Report**

DATE: 2007

CITATION: Carlson, Paul J., Jeffrey David Miles, Adam M. Pike and Eun Sug Park. Texas Transportation Institute; Texas Department of Transportation; Federal Highway Administration, 158p.

ABSTRACT: This report details the completion of a 30-month project investigating wet-night and contrast pavement markings. The first year report contains the literature review on wet-night markings and the Phase I effort on wet-night pavement markings. This report contains the Phase II effort on wet-night pavement markings, a benefit-cost analysis, and a study of contrast markings. Phase II effort consisted of expanding the study design from Phase I to include additional wet-night pavement marking products, the effects of glare and dry pavement on detection distances, and a benefit-cost analysis with respect to the use of different pavement marking systems to accommodate drivers under wet-night conditions. In the contrast study, a literature review of contrast markings, a state-of-the-practice with respect to contrast markings, and a study of driver understanding and preference with respect to contrast markings were all conducted. After studying multiple wet-night pavement marking products and standard pavement marking products used in the state of Texas, it was found that reflectorized raised pavement markings provided the most preview time under wet-night conditions. The rumble strip and the use of bigger beads such as Type III do provide improved wet-night detection distance, and in reference to cost, the use of bigger beads on a flat line, or a rumble strip in conjunction with RRPMs provides an effective wet-night performance. Contrast markings were found to be used in 64 percent of the districts in Texas and in 64 percent of the responding states. The most frequently used contrast marking design is the bordered design where a white marking is highlighted with black markings along the longitudinal sides. While driver preference suggests that the shadow design is less preferred to the bordered design, the shadow design is normally a more cost-effective design, considering maintenance of the marking. The findings show that the bordered design is preferred. While this design is currently provided with tape products, which have a high initial cost, a non-tape marking alternative is the shadow design, which has fewer maintenance concerns than other non-tape applications. The use of only these two designs is also recommended to limit the number of contrast marking designs in hopes of minimizing driver confusion (this study showed that some drivers do not understand the meaning of the contrast markings).


**Pavement Marking Visibility Requirements During Wet Night Conditions**

DATE: 2006

CITATION: Gibbons, R. B. Virginia Tech Transportation Inst.

ABSTRACT: This study investigated the performance of pavement markings in wet night
conditions. Typically, performance will decrease in wet conditions. The degradation is a result of flooding of the marking optics and a change in the optical media, thereby reducing retroreflectivity and the visibility distance. Several technologies are available to improve the visibility of markings under wet conditions. This study used four technologies and evaluated them in a dynamic situation. In the experiment, vehicles were driven by older participants and visibility was measured based on the detection distances of the beginning or ending of a continuous edge marking. The results indicate that a specifically designed wet retroreflective tape performed better than the currently used paint and glass bead technology. Paint with large glass beads and profiled thermoplastics also showed an improvement over the standard paint and glass bead technology. A relationship between retroreflectivity and the detection distance was found, which was used to postulate a minimum required value for visibility during wet night conditions. A value of 200 cd/m²/lx appears to provide a reasonable detection distance for a minimum performance requirement.


Wet Night Visibility of Pavement Markings: Executive Summary
DATE: 2004
ABSTRACT: The research sought to answer the following questions: what level of retroreflectivity do drivers need under rain conditions and what levels of retroreflectivity are current pavement markings and markers capable of producing under various rain conditions? The rain conditions include the period during rainfall of various intensities within a defined range and the recovery period (drying) after rain has stopped. The research also sought to test the suitability of the American Society for Testing and Materials (ASTM) measurement methods for wet pavement marking retroreflectivity. The findings should then be used to develop performance measures for evaluating wet night retroreflectivity of pavement delineation devices and a performance-based specification that is based on the visibility needs of motorists during wet night conditions, perhaps even one for inclusion in the Virginia DOT’s Road and Bridge Specifications.

Wet Night Visibility of Pavement Markings
DATE: 2004
ACCESS: Please see the VDOT Research Library

Wet Night Visibility of Pavement Markings: A Static Experiment
DATE: 2005
ABSTRACT: Thirty-three participants, all 60 years of age and older, evaluated the visibility of six different pavement marking materials under a simulated rain system operating at 0.8 in. (20 mm) of rain per h at night. Evaluation consisted of counting the number of skip lines visible from both a sedan and truck tractor, under headlight illumination only. Participants also evaluated markings from the sedan under dry conditions at night. Visual observations were compared with measured retroreflectivity of pavement marking materials, measured luminance of pavement marking materials at 30 m, and calculated retroreflectivity at 30 m, on the basis of measured luminance and illuminance provided by vehicle headlights. Data showed a high degree of correlation between the visibility distance of a marking material and the log of both the measured retroreflectivity and the calculated retroreflectivity. A definitive level of retroreflectivity required to meet drivers’ needs in wet night conditions was not found in the investigation and is now the subject of further study. There was also a high degree of correlation between measured and calculated values of retroreflectivity under simulated rain and measurements with the use of two current ASTM test methods, E2176 and E2177. In a second experiment, six original participants evaluated the visibility of the pavement marking materials for a 10-min
interval following cessation of simulated rain. Results of the second experiment indicated
significant differences in the time required for the visual performance of a pavement
marking material to recover from rain for paint and bead products versus that of other
pavement marking materials under evaluation.
ACCESS: http://dx.doi.org/10.3141/1911-11

Wet Night Visibility of Pavement Markings: Dynamic Experiment
DATE: 2007
CITATION: Gibbons, Ronald B. and Jonathan Hankey. Transportation Research Record:
ABSTRACT: Fifty-three participants evaluated the visibility of four different pavement
marking materials under a simulated rain system operating at 0.8 in. (20 mm) of rain per
hour at night while driving a vehicle on a closed test track. The conditions tested include a
variable lighting condition, glare, pavement types, and two different vehicle types. The
evaluation consisted of determining the detection distance of a start or an end point of a
white 4-in. edge line. Results showed that lighting improved visibility and mitigated the
effects of glare. Results also showed that the wet retroreflective tape provided the longest
visibility distance, followed by equivalent performance of profile thermoplastic; large glass
beads with standard paint provided the shortest visibility distance. The detection distance
was compared with the retroreflective performance of the pavement marking technology.
It was found that a log-linear relationship exists between the retroreflectivity and the
detection distance. It was also found that the level of retroreflectivity provided by the
materials tested did not provide adequate visibility distance for a sedan with a 2-s visibility
time at speeds greater than 45 mph.
ACCESS: http://dx.doi.org/10.3141/2015-09

Performance Evaluation of Pavement Markings Under Dry, Wet, And Rainy
Conditions In The Field
DATE: 2004
CITATION: Aktan, F. and T. Schnell. Transportation Reserach Record, Transportation
Research Board, 1877, p.-38-49. Appears in Transportation Research Record No. 1877.
ABSTRACT: The nighttime visibility of three types of pavement markings--a large-beaded
permanent pavement marking and two types of patterned pavement marking tapes, one
with high-index beads and the other with mixed high-index beads--was evaluated under
dry, wet (just after rainfall), and simulated rain conditions (ongoing 1-in./h rainfall). The
dependent measures were pavement-marking end-detection distance and retroreflectance.
The experiment was conducted at the 3M Transportation Research Center in Cottage
Grove, Minnesota. This facility features a level and straight roadway section where 1-in./h
rainfall can be simulated. Eighteen subjects between the ages of 55 and 75 participated in
the study. The participants drove an experimental vehicle on dry and wet test sections
with the pavement-marking treatments. Participants noted the earliest point at which they
were able to see the end of the right edge line pavement markings. The retroreflectance of
each pavement-marking material was also measured with three handheld
retroreflectometers under the three weather conditions, according to ASTM E1710 (dry),
ASTM E2177 (wet recovery), and ASTM E2176 (continuous wetting) standards. In terms of
end-detection distances, the patterned tape with mixed high-index beads performed best
under all three weather conditions. The paint and large-bead pavement markings were
comparable to the tape with high-index beads under wet and rainy conditions. Under dry
conditions, paint and large-bead pavement markings performed the worst. The detection
distances seemed to strongly correlate with the standard retroreflectances only if the
retroreflectance data from the corresponding test method are used.
ACCESS: http://dx.doi.org/10.3141/1877-05

Pavement Marking Photometric Performance and Visibility Under Dry, Wet, and
Rainy Conditions: Pilot Field Study
DATE: 2006
CITATION: Burns, David M. Neil Hodson, Dale Haunschild and Dave May. Transportation
Research Record: Journal of the Transportation Research Board, Transportation Research
ABSTRACT: Pavement markings are a fundamental component of the roadway safety infrastructure. They play an especially important role at night, when there are fewer visual cues for the driver. Although progress is being made in pavement marking management practices, advances in materials are still needed to fulfill driver needs for nighttime visibility and guidance under all weather conditions, especially wet and rainy conditions. This study was conducted to investigate the relationship between the photometric properties of pavement markings and their visual performance under dry, wet, and rainy conditions. For this pilot study four levels of material performance were created by a systematic reduction of the retroreflective efficiency of a single wet retroreflective tape construction. The nighttime visibility of the pavement marking materials was evaluated under dry, wet (just after rainfall), and rainy conditions. Eight 4-in. skip lines were viewed on the road in a standard 10-ft skip line and 30-ft gap pattern. The dependent measures were the number of skips visible, the subjective rating of the skip line relative to its adequacy for driver guidance, and average skip line luminance as a function of distance. Under rain conditions of 0.5 in./h, a material with an retroflected luminance in the rain (RL-rain) of 30 mcd/m²/lux (per ASTM E2176-01) was found to provide an inadequate preview time and was rated as providing unacceptable visibility. A good correlation ($R^2 = 0.94$) was obtained for the instrumental measurement of RL and the number of skips seen. The luminance data suggest that an average pavement marking luminance greater than ~0.5 cd/m² is required for a skip line to be visible to the driver at night.

ACCESS: http://dx.doi.org/10.3141/1973-16

Evaluation of Visibility of Pavement Markings in Wet-Night Rainy Conditions and Appropriateness of Associated Measurement Techniques
Transportation Research Board 86th Annual Meeting DATE: 2007
ABSTRACT: Researchers evaluated the performance of 18 different pavement markings in a wet-night condition to obtain a better understanding of how a wide range of markings perform under such conditions and how their performance can be assessed. Three metrics were obtained and analyzed: 1) retroreflectivity measurements, 2) dynamic detection distance measurements, and 3) luminance measurements. The retroreflectivity measurements were made under a variety of conditions including dry, wet recovery, and 12 levels of continuous wetting ranging from 0.28 inches per hour to over 20 inches per hour. Detection distance measurements were made in a dynamic setting in which 30 research participants drove through a rain tunnel that was calibrated to produce realistic rainfall rates (0.28 and 0.87 inches per hour). Finally, the luminance of the markings was measured at 30-meter geometry under realistic rainfall rates. The relationships between the measured detection The results indicate the weakness of ASTM E2176 and provide recommendations for further study.
ACCESS: Please see the VDOT Research Library

Evaluating the Retroreflectivity of Pavement Marking Materials Under Continuous Wetting Conditions
DATE: 2007
ABSTRACT: Wet weather performance of pavement markings has received increased emphasis with the availability of new products designed specifically to improve nighttime visibility in wet weather conditions. Procedures for measuring the performance of these and standard marking materials are found in ASTM E1710, E2176, and E2177, which describe retroreflectivity measurement in dry, continuous wetting, and recovery conditions, respectively. Research comparing the retroreflectivity values measured for 18 different marking samples in 14 measurement conditions is described. Each sample was measured according to the three ASTM procedures, plus an additional 11 rates of continuous wetting. In addition, analysis was done of 20 years of Texas rainfall data to
gain an understanding of the relationships between actual rainfall rates and the rates specified in E2176. Findings indicate that while the allowable rainfall rate in E2176 ranges from 6 to 14 in./h, 88% of rainfall events produced maximum rates less than 0.75 in./h. A wide variability was found in the retroreflectivity values of materials as a function of the wet condition. For most markings, the retroreflectivity level decreases as the rainfall rate increases, but changes in retroreflectivity were not consistent for the different samples. Also, an analysis of the effect of cross slope on wet retroreflectivity measurements indicated that it has a major impact on the measured values. Findings suggest that the range of conditions permitted by E2176 brings into question the ability to use this procedure to compare material retroreflectivity in a standardized manner.

ACCESS: http://dx.doi.org/10.3141/2015-10

**Computer-Based Modeling To Determine The Visibility And Minimum Retroreflectivity of Pavement Markings**

DATE: 2000
ABSTRACT: The Federal Highway Administration was mandated by the U.S. Congress to establish in-service levels of minimum pavement-marking retroreflectivity and commissioned research to determine the minimum in-service level from a driver's point of view. Computer Aided Road Marking Visibility Evaluator (CARVE) was developed and refined to systematically investigate drivers' visual needs in terms of nighttime pavement-marking visibility and to allow the formulation of minimum retroreflectivity recommendations. The components within CARVE and the methods, algorithms, and equations that are used to determine the visibility distance of a given pavement-marking treatment are presented and discussed. CARVE systematically manipulates the pavement-marking efficiency up and down using a bisecting-search algorithm until the desired minimum required preview distance for selected conditions is achieved. Future expansions of CARVE, or the development of models that supersede it, may require additional research to investigate the wet-weather visibility of pavement markings, the effects of combined treatments consisting of pavement markings and raised reflective markers, and the visibility in inclement weather such as fog and blowing snow.
ACCESS: http://dx.doi.org/10.3141/1708-06

**Nighttime Visibility And Retroreflectance of Pavement Markings In Dry, Wet, And Rainy Conditions**

DATE: 2003
ACCESS: Please see the VDOT Research Library

**Nights on the Road: Companies are Constantly Producing and Refining Products to Aid Safe Night Time Driving**

DATE: 2008
ABSTRACT: This article describes a number of products that are designed to improve highway safety in nighttime conditions. The first product is a type of road marking system that provides a high performance blend of reflective beading that allows for aided retro-reflectivity of two-component cold plastics, solvent-based paints, waterborne paints, and thermoplastics. The next technology, which was developed with a grant from the Federal Highway Administration's (FHWA) Life Technology Partnership Program, uses reflective optical materials embedded in pavement that allow for high-visibility to drivers on that surface in wet conditions. The currently developing technology will be designed to be deployed in work zones on a temporary basis. The last system is a granulometric repartition glass bead product that provides a high level of retro-reflectivity during the night time according to contextual considerations.
ACCESS: Please see the VDOT Research Library
Follow the Line
Rocks and Bridges. 2000/04 DATE: 2000
ABSTRACT: Over the past 15 years, industry and road authorities in Europe and North America investigated ways to increase wet night visibility and minimize retroreflectivity risk of road markings. Their efforts led to profiled markings of different vertical geometry. Profiled marking configurations include both continuous lines and discontinuous structure designs. Continuous markings resemble conventional high build lines of typical thickness, but include a raised portion of up to 0.5 in. that protrudes above the rain level to provide retroreflectivity for the vehicle driver. Structure markings consist of irregular small agglomerates of typical 0.2 in. thickness available in several patterns. Because the driver sees the structure marking in passing at a very flat angle, only the front sides of the agglomerates reach their fields of vision. Dark gaps are not perceived while the white areas are perpendicular to the driver generating an impression of a brighter white than flat lines. During wet conditions, the rain is channeled away from the agglomerates allowing for continuous visibility. Methacrylate reactive resins are suited for the formulation of profiled markings. They are blended with fillers, glass beads, pigments, and additives to create highly thixotropic materials that hold their shape during application. A powder hardener additive cures these systems in 5-20 minutes at temperatures ranging from 41 deg F to 122 deg F. The good adhesion of methacrylate systems to asphalt and concrete substrates, combined with excellent bead retention, results in markings that hold retroreflectivity values over many seasons. Worldwide use of methacrylate markings for profiled applications has increased significantly in recent years.
ACCESS: Please see the VDOT Research Library

Reflecting on Highway Safety
DATE: 2003
ABSTRACT: This article discusses the work of the American Society for Testing and Materials (ASTM) Subcommittee on Highway Traffic Control Materials. This subcommittee develops relevant standards for materials such as sign sheeting, pavement marking materials and pavement markers. For safety reasons, it is critical that the information conveyed by signs and pavement markings be available both day and night, regardless of the availability of overhead lighting, against backgrounds of varying complexity and under all weather conditions. Three issues are discussed in detail: consistency of pavement marking color, high visibility signs for work zones, and wet reflective pavement markings. The subcommittee has developed various standards and test methods to address these issues in order to ensure visibility.
ACCESS: Please see the VDOT Research Library

Manual on Uniform Traffic Control Devices
DATE: 2003
CITATION: Federal Highway Administration.
ABSTRACT: The Manual on Uniform Traffic Control Devices, or MUTCD defines the standards used by road managers nationwide to install and maintain traffic control devices on all streets and highways. The MUTCD is published by the Federal Highway Administration (FHWA) under 23 Code of Federal Regulations (CFR), Part 655, Subpart F. ACCESS: http://mutcd.fhwa.dot.gov

III. RESEARCH IN PROGRESS

Evaluation of Wet-Weather Retroreflectivity
CITATION: Oregon State University, Corvallis.
ABSTRACT: Pavement markings are vital to traffic operations and the safe negotiation of drivers through the transportation system. During wet weather conditions a minimum level of retroreflectivity (luminance) is necessary to ensure adequate performance and to meet the needs of older drivers that require higher levels of retroreflectivity. Having pavement
marking materials that perform well in wet weather is particularly important in Oregon. This study will help determine how the Oregon Department of Transportation (ODOT) testing and specifications can be adjusted to accommodate explicit consideration of wet pavement marking retroreflectivity, and will develop a conceptual framework for the selection of pavement markings (excluding waterborne paints) that incorporates wet pavement.

Research in Progress - Status: Proposed
ACCESS: http://rip.trb.org/browse/dproject.asp?n=17265

Planning, Developing and Implementing the Iowa Pavement Marking Management System (IPMMS)
CITATION: Iowa State University.
ABSTRACT: Selection of the most cost effective pavement marking system in a given situation depends on three main factors: 1) retroreflectivity, 2) durability and 3) cost. Several subordinate factors stem from these, such as type of road surface, volume of traffic, orientation with respect to traffic, quality control at the time of installation, winter sanding and snow removal practices, schedule of pavement maintenance activities, and inconvenience experienced by the traveling public during installation. In general, conventional paints are used in areas having low traffic volumes and infrequent winter maintenance; products of higher durability are used in areas having more traffic and more instances of sanding and plowing. Efforts are underway in other states to improve the cost effectiveness of pavement marking programs. This includes collecting and storing retroreflectivity data, developing contracts that include warranty specifications, and investigating ways to develop a pavement marking management system. This project is aimed at development of an Iowa pavement marking management.
Research in Progress - Status: Active
ACCESS: http://rip.trb.org/browse/dproject.asp?n=19325

Raised Pavement Markers (RPM) Durability Evaluation
CITATION: Mississippi State University.
ABSTRACT: Raised pavement markers (RPMs) have been used for many years to improve the day and night visibility of traffic facilities. According to the FHWA Roadway Delineation Practices Handbook, RPMs offer the following advantages over standard painted markings: (1) increased retroreflectivity in wet weather conditions; (2) increased durability; (3) increased audible tone produced by the vehicle making contact with the RPMs; and (4) increased directional control through the use of varying colors. While the RPMs offer many advantages over painted marking materials, the higher initial cost is their main disadvantage. Mississippi Department of Transportation (MDOT) has expressed concern that the current RPM usage protocol needs to be evaluated to insure the most cost effective protocol possible. Concern has been expressed that the observed increased loss of RPMs may be a result of the pavement surface type, pavement age and placement location. Additionally, there is a question regarding the time available for RPM application after adhesive application. The research proposed will involve reviewing MDOT District RPM inventory data. The percent of RPMs lost will be used as the study response variable. An analysis of project variables will be conducted to determine which factors most influence RPM loss over time. Specifically, data will be analyzed with regards to several research factors documented as follows: (1) pavement type (HMA or PCC); (2) pavement age; (3) highway type; (4) RPM type; (5) RPM adhesive type; and (6) application temperature. The study will provide MDOT with information regarding durability of RPMs. Research in Progress Status: Terminated
ACCESS: http://rip.trb.org/browse/dproject.asp?n=10001

Use of Snowplowable Reflective Pavement Markers for Effective Delineation, Final Report
CITATION: North Dakota Department of Transportation.
ABSTRACT: Of the total of 120 markers placed, only five markers were damaged enough to effect their visibility. The raised markers were able to improve the delineation of the lanes at the US 52 installation but were not in a position to improve delineation at the
The application of a chip seal greatly reduced the visibility of the raised markers at the US 52 installation. Raised markers are recommended for locations with unusual or unexpected geometry.

Use of Snowplowable Reflective Pavement Markers for Effective Delineation, Third Evaluation Report
CITATION: North Dakota Department of Transportation.
ABSTRACT: All of the reflectors are still effective and functioning as designed. The evaluation period has included below average snowfall so the "plowability" of the markers have not been fully tested. The markers show up very well after sanding even when the paint markers are totally obliterated with sand. Some markers have cracks at one of the "ears" that the marker rests on.

Pavement Markings State of the Practice Study
CITATION: Pennsylvania State University.
ABSTRACT: The purpose of this project is to identify pavement marking products, practices, and "lessons learned," in other states with climates and winter maintenance activities similar to those found in Pennsylvania.