AN INVESTIGATION INTO MEASURING THE CONTINUOUS WETTING RETROREFLECTIVITY VALUES OF PAVEMENT MARKINGS

A Thesis Proposal

by

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INTRODUCTION

At night, pavement markings working in conjunction with the vehicle headlights are typically the primary means of providing guidance information to the driver. Therefore properly placed and properly maintained pavement markings are critical for safe driving (1). The Manual on Uniform Traffic Control Devices (MUTCD) requires pavement markings to be retroreflective if they are to be visible at night, unless sufficient ambient lighting is provided to make the markings visible. All markings on Interstate highways are required to be retroreflective (2).

As traffic control devices, pavement markings serve several purposes. To be effective and serve the intended purposes, the markings must be visible far enough in advance to provide adequate time for reaction to occur and be visible in the periphery to aid in short range lane navigation (3). When properly implemented, these purposes can include the following (2,3,4):

- To regulate, guide and warn traffic.
- To supplement other traffic control devices.
- To provide proper positioning of vehicles.
- To separate opposing streams of traffic.
- To warn of restricted sight distances ahead.
- To improve traffic flow.

In wet night conditions, most pavement markings appear less bright than they would appear during dry night conditions. These wet pavement markings are unable to provide their full retroreflectivity values due to the accumulation of water on the marking surface. The accumulation of water causes the light from the headlight to be scattered instead of being retroreflected back toward the driver. The impacts of water on the markings in wet night conditions results in shorter detection distances. The shorter detection distances create more demanding driving situations and less safe driving environments.

PROBLEM STATEMENT

The Texas Transportation Institute (TTI) is conducting a study to evaluate the performance of pavement markings during wet night conditions. The main objectives for the study are to relate the detection distances and the retroreflectivity values of the markings during the wet night conditions. The detection distances are measured for individual subjects as they view the markings in the simulated rain environment at night, under three rainfall intensities. The retroreflectivity values are measured using a handheld retroreflectometer.

The American Society for Testing and Materials (ASTM) has three standards for measuring retroreflectivity of pavement markings. ASTM E 1710-97 is for dry conditions, ASTM E 2177-01 is for recovery conditions and ASTM E 2176-01 is for continuous wetting conditions (5, 6, 7). All three standards will be used to evaluate the markings, but ASTM E 2176-01 will be explored in depth. This research is being proposed to further study the research project that is being conducted by TTI.

Currently ASTM E 2176-01 uses a rainfall rate of approximately 9.3 inches per hour, which is much higher than any realistic expectation of rainfall on any highway. Since the test is intended to provide predictive performance of pavement markings in actual roadway conditions, the high rainfall rate poses a concern and will be investigated in this proposed study. This study will explore various rainfall intensities from less than 1 inch per hour to over 14 inches per hour,
and compare the retroreflectivity values at these rainfall rates to the detection distances obtained from the TTI study.

**RESEARCH OBJECTIVES**

The objective of the proposed research is to evaluate the predictive performance of ASTM standard E 2176-01 in terms of the wet retroreflectivity measurements provided by following the procedures outlined in the standard. The wet retroreflectivity measurements will be evaluated and compared to the detection distances from the TTI study and the correlation of the values will be found. Additional wet retroreflectivity measurements, more consistent with typical rainfall intensities, will be obtained and analyzed. The results will be compared to the results found using the ASTM E 2176-01 standard. If warranted, changes will be suggested for the ASTM standard to try and achieve a better correlation with the detection distance values. The specific goals for this research are:

- Evaluate the predicted performance of ASTM E 2176-01 by following the procedures outlined in the standard and correlating the measured retroreflectivity values to the detection distance values for a range of pavement marking materials.
- Evaluate different rainfall rates that are more consistent with typical rainfall intensities than those of ASTM E 2176-01. Find the rate that results in the retroreflectivity values that best correlate with the detection distances.
- If warranted, make recommendations for improvements to ASTM E 2176-01 to provide an accurate and simple testing procedure for measuring the retroreflectivity of pavement markings in rainy conditions.

**BACKGROUND**

Pavement markings are typically made of materials such as thermoplastic, paint, epoxy, or tape products. Glass beads are either mixed with the material, sprinkled on top when wet, or sprinkled on top of mixed material to help improve nighttime visibility (3). The glass beads should be imbedded enough so that they adhere to the material but not over imbedded so they can provide retroreflectivity to the marking. The glass spheres allow the light to enter them and then reflect that light back out, some of which is retroreflected which allows the driver to see the marking. Figure 1, shows a glass bead imbedded in a pavement marking retroreflecting light.

Over time, the markings retroreflectivity will decrease. Traffic and weather cause the retroreflectivity to decrease by dislodging beads from the marking and the buildup of dirt on the marking also keeps light from being retroreflected. Water on the marking will also reduce retroreflectivity due to the light being reflected in a specular fashion before ever reaching the glass beads. More water present on the marking causes a greater reduction in retroreflectivity. Larger glass beads have been found to provide better nighttime visibility in the rain than standard beads (3). Larger beads perform better due to their increased size, allowing them to not be submerged in water as easily as smaller beads.
Typically the two most important criteria for evaluating a pavement marking are its nighttime visibility and proportion of missing or non-functional surface area (2). The two forms of evaluating markings are subjective and objective (2,4). Subjective analysis grades the marking on a scale based on the perceived adequacy of the marking. Objective analysis of the marking uses instruments to quantitatively measure values of the pavement marking, i.e. retroreflectivity or luminance values.

Retroreflectivity values are measured with either a handheld or mobile retroreflectometer. These devices measure retroreflectivity at a 30-meter viewing geometry. A 30-meter viewing geometry simulates the effectiveness of a marking that is located 30 meters in front of the vehicle. The entry and observation angles that represent the 30-meter geometry are the standard values used by ASTM and the European Committee on Standardization (CEN). Figure 2 shows how a 30-meter geometry is represented (8).

The night time performance of a pavement marking is most often represented by measures of retroreflectivity and luminance. Retroreflectivity measured in units of millicandels per meter squared per lux (mcd/m²/lx) is the quantitative measurement typically used to indicate the nighttime visibility of a marking. Retroreflectivity of pavement markings is a measure of the amount of light from the pavement marking that is reflected back toward the driver. Luminance is measured in units of candelas per meter squared (cd/m²) and measures the light intensity per
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unit area coming from the pavement marking. Luminance is a measure of the amount of light available for the driver to see.

Potters Industries and Advanced Retro Technology have developed a handheld retroreflectometer called the MX30. The MX30 is able to accurately measure retroreflectivity values from 20 to 1200 mcd/m²/lx (9). The MX30 can take accurate readings over a wide range of ambient conditions (9, 10). Figure 3 shows what the MX30 looks like and how it is placed on a pavement marking while taking the retroreflectivity measurement (11). The open ended design where the measurements are taken, allow for continuous wetting measurements, as well as dry and wet measurements.

![MX30 Handheld Retroreflectometer](image)

**Figure 3. MX30 Handheld Retroreflectometer (11)**

Retroreflectivity is associated with visibility; the higher the retroreflectivity value then generally the more visible the marking will be (3,4). The more visible a marking is the further the visibility distance will be and thus a longer preview time. Studies have shown pavement markings exhibit a positive correlation between detection distance and retroreflectivity levels (12,13,14).

A recent study conducted by the Virginia Tech Transportation Institute (VTTI) studied wet night pavement marking performance (15). As part of their research, ASTM E 2176-01 was used to measure the retroreflectivity values of the pavement marking materials. The results of the VTTI study indicated that the ASTM test was a very good test due to the high correlation values that were obtained between the visibility distances and retroreflectivity values.

There were several limitations with the VTTI study though. The visibility distances were found during a static test, thus the subjects were not moving while viewing the markings. This is being addressed in a dynamic follow up study currently underway at VTTI. The visibility distances were found by counting skip lines, which will leave room for error in actual distances the marking materials, can be seen. This is also being addressed buy using end detection distances during their dynamic study. The number of samples studied was small, so it does not show that the test can cover a wide range of marking products. The markings studied cover a large range performance wise, but the type of materials covered lesser of a range. Also ASTM test E 2176-01 may not have been properly performed according to the procedure they used, which will cause errors in the retroreflectivity values.

With the VTTI study being the largest study thus far to directly compare the ASTM E 2176-01 test with visibility distance values, there is not much history to say the current ASTM
RESEARCH STUDY DESIGN

The research objectives will be fulfilled by following the study design. The study design includes the following tasks, each of which are described below.

1. **Review the Pertinent Literature:**
   - A portion of the literature has been reviewed for this proposal. A thorough literature review concerning wet retroreflectivity measurements and literature concerning the tasks at hand is to be conducted. Comparisons of retroreflectivity values to detection distances (objective ratings), or subjective ratings will be most important. The literature review will also explore the three ASTM procedures for measuring retroreflectivity. Literature regarding the MX30 retroreflectometer will also be further reviewed so that the device is properly implemented.

2. **Identify Data to be Collected:**
   - Data collection will include dry, recovery and continuous wetting retroreflectivity values. The values will be collected for various pavement marking materials so that a range of markings will be covered by the study. Marking materials will include waterborne paint, epoxy and thermoplastic all with various bead types. Pavement marking tape products and profiled markings will also be studied. For comparison purposes, dry retroreflectivity values, recovery retroreflectivity values and continuous wetting retroreflectivity values will be measured for each marking material in accordance with the ASTM testing specifications. For the continuous wetting measurements, multiple sets of data will be collected. The continuous wetting measurements must be found for several levels of rainfall intensity on the markings to achieve the objectives of this study. Detection distance data for each marking will be collected during the TTI study, and used in the analysis.

3. **Design Experimental Study:**
   - The study will require two parts. The first part was conducted by TTI and found the detection distance values of the pavement marking samples. The second part will be collecting retroreflectivity values associated with the pavement marking samples. Each part is discussed in detail below.

*Detection Distance Values:*

The detection distances for each marking material were found during the TTI study. The TTI study was conducted separately from this proposed research but the data collected will be used for correlation. All human subject waiver and consent forms have been managed by TTI, as human subjects are not part of this proposed research extension of the TTI study. The TTI study was conducted at night in the rain simulator constructed at the Texas A&M University Riverside Campus. The rain simulator can be seen in Figure 4 and Figure 5. The vehicle the subjects drove was a 2004 Ford Taurus. All subjects were required to pass a vision test and hold a valid driver’s license. Both young
and older drivers were studied. Thirty-four subjects drove 12 times through the rain simulator at 30 miles per hour and viewed the pavement markings, while varying rain intensities were falling. The subjects determined when they could first detect each pavement marking material. The detection distance was found for each marking material being studied by using a calibrated distance measuring instrument (DMI). Each marking material was removable to allow for a new material to be placed in the rain simulator, for subsequent passes of each subject. Distracter markings were placed at the edge of the test course on several runs to keep the driver from predicting marking placement. The vehicle used to transport the marking materials and the substrate that the materials were applied to can be seen in Figure 6.
Retroreflectivity Values:

The three ASTM standards will be used to collect the retroreflectivity of each marking material that is studied. As previously stated, ASTM E 1710-97 is for dry conditions, ASTM E 2177-01 is for recovery conditions and ASTM E 2176-01 is for continuous wetting conditions.

In addition to the three ASTM specifications, several sets of retroreflectivity data will be collected using a modified ASTM E 2176-01 specification. To fulfill the objectives of the proposed research, several rain intensities other than the one currently being used by the ASTM specification are to be measured. The varying rain intensities will show the performance of the marking materials under various rainfall testing conditions. The retroreflectivity values of the marking materials will also be found in the simulated rain at the rain simulator.

A brief overview of the ASTM testing procedures will be outlined below. These procedures will be followed for all measurements of each specification, as to not introduce other variables into the study. Retroreflectivity values will be measured along each of the test samples in the direction of travel. Multiple measurements will be taken and averaged to find the retroreflectivity value to be associated with each marking material, for each of the testing procedures.

**Dry Retroreflectivity:** This method will follow ASTM E 1710-97. Each sample will only be measured when it is completely dry.

**Recover Retroreflectivity:** This method will follow ASTM E 2177-01. These measurements will be taken after the sample has been covered in water and allowed 45 seconds to recover from the flooding. Each retroreflectivity measurement will be taken after a separate flooding and recovery of the marking. Four retroreflectivity readings will be taken for each sample.

**Continuous Wetting Retroreflectivity:** This method will follow ASTM E 2176-01. These measurements will be taken while the sample is continuously being sprayed with water and the retroreflectivity value is allowed to become steady for the spray rate. In addition to the ASTM method, the proposed rainfall intensity
variation will also be conducted in the same manner. The setup will be modified to allow for various rain intensities to be sprayed onto the markings. Six retroreflectivity reading will be taken for each sample.

4. **Collect Field Data:**

   In order to collect the data, several pieces of equipment will be used to collect and/or aid in data collection. The main instrument for data collection will be the handheld retroreflectometer. For this study, the MX30 handheld retroreflectometer will be used to collect all of the retroreflectivity data. To provide a constant rate of spray for the continuous wetting test, a spray device will be constructed to allow for consistent and adjustable flow rates. In conjunction with this device, a rain shield will also be constructed to protect the MX30 from the spray. Figure 7, shows the retroreflectivity measurement setup, including the MX30, rain shield and spraying device.

   ![Figure 7. Retroreflectivity Measurement Setup](image)

   - Dry retroflectivity data will be found for each test sample using the MX30
   - Recovery retroreflectivity data will be found for each sample using the MX30, a bucket of water and a stop watch to allow for a constant time for the water to runoff the sample.
   - Continuous wetting retroreflectivity data will be found for each sample using the MX30, the spray device and the rain shield. This data will be collected at several rainfall rates. The retroreflectivity data to be collected in the rainmaker will be collected using the MX30 and a protective cover for the MX30 to keep the rain off of the instrument.

   All retroreflectivity data will be collected and recorded for each sample and the detection distances found during the TTI study will be given to each sample. These two pieces of data are the basis of the analysis and are what need to be collected.
5. **Data Analysis:**

The analysis of the data will be conducted in the following manner to meet the research objectives.

- The collected data will be reduced to remove any noticeable outliers and to remove data that was collected in error. An example of these circumstances would be retroreflectivity values collected before the retroreflectivity value stabilized.
- Descriptive statistics for the retroreflectivity values and detection distance values for each sample will be used. The mean and standard deviation will be found for both sets of data. The 75th percentile value will also be found for the detection distance values. The detection distance values will be taken from the TTI analysis of the detection distance data.
- Retroreflectivity and detection distance of the samples will be correlated. The higher the level of correlation the better, as retroreflectivity is a good indicator of detection distance, based on the literature. Correlations will be made for all measured rainfall intensities. Correlations will also be made for subsets of the sample types.
- Detection distances and retroreflectivity levels for the various rain intensities collected at the rainmaker can be correlated with each other. The retroreflectivity values found from the continuous wetting testing will also be correlated to the retroreflectivity values measured in the simulated rain.

6. **Prepare Thesis:**

After conducting the data analysis a summary of the findings will be determined and analyzed. Recommendations based on the predictive performance of ASTM E 2176-01 for measuring a range of pavement markings will be made. If warranted, recommendations of modifications to ASTM E 2176-01 will be made. Each task in the study design will be included in the final Thesis. The Thesis will be prepared in accordance with Texas A&M University Policies.

**POTENTIAL BENEFITS OF STUDY**

The main benefit of the research would be recommending changes to the ASTM E 2176-01 testing procedure that would provide results that correlate more closely to those actually experienced in the field. This benefit will only occur if the current ASTM standard is found to not correlate well with a wide range of pavement marking materials at the currently used rain intensity. A standard that could provide better predictive performance of a pavement markings retroreflectivity during wet night conditions will allow transportation agencies to replace markings that have fallen below suggested levels of retroreflectivity at the proper time. This will provide a safer driving environment during wet night driving conditions.
REFERENCES


8) Facet Technology Corp. The Automated Determination of Sign and Pavement Marking Retroreflectivity from a Moving Platform. Eden Prairie, MN.


