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16. 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 stripe 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 stripe 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).

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The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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CHAPTER 1: INTRODUCTION

Longitudinal pavement markings are one of the most important means of communicating the separation of lanes of travel and the roadway alignment. Hence, it is important to design and use pavement markings that are both durable and cost-effective while also being able to provide effective lane guidance under normal and poor visibility conditions. In particular, numerous new types of pavement marking systems have been developed and deployed on an experimental basis to evaluate them under normal and poor visibility conditions, such as rain or poor pavement contrast. What has been lacking is research to evaluate the potential benefits of these pavement marking systems.

This report documents a 30-month research effort to analyze wet-night and contrast pavement marking systems for their potential benefit and cost-effectiveness. Furthermore, the findings from this project have helped develop recommendations that can be used to help TxDOT develop effective guidelines on the use and specification of wet-night and contrast pavement markings. This report is the second report developed for this project. The first report, *5008-1*, contained the results from Phase I of the wet-night pavement marking analysis and an in-depth review of pertinent literature related to wet-night pavement marking systems (*1*). This final report contains the results from Phase II of the wet-night pavement marking analysis, a benefit-cost analysis of wet-night pavement markings, a literature review on contrast markings, a state-of-the-art with respect to contrast markings, and an assessment of driver understanding and preference with respect to contrast markings. The titles of each of the chapters from both reports are listed below to better enable the reader to navigate this research effort.

First-Year Report (*5008-1*)

Chapter 1	Introduction
Chapter 2	State-of-the-Art of Wet-Night and Contrast Pavement Markings
Chapter 3	Rain Analysis
Chapter 4	Wet-Night Pavement Marking Study Design
Chapter 5	Wet-Night Pavement Marking Preliminary Results
Chapter 6	Findings and Planned Year Two Activities

Final Report (*5008-2*)

CHAPTER 2: PERFORMANCE OF PAVEMENT MARKINGS – RETROREFLECTIVITY AND VISIBILITY

INTRODUCTION

This chapter describes the work completed to assess the performance of pavement markings under wet conditions. This portion of the research was completed in two phases. Phase I was described in the first report, *5008-1* (*1*). Applicable findings from Phase I are included in this report, but the literature review and entire analysis from Phase I are not repeated in this report. This chapter describes the Phase II study design, including the data collection, reduction, and analyses.

In particular, the analyses focus on the differences and subtleties of dry, recovery, and wet retroreflectivity measurements. They also include statistical testing of the measured detection distances in dry and wet-night conditions. The statistical testing was designed to investigate relationships such as wet retroreflectivity measurements and detection distances, as well as the impact of wider lines on detection distances.

A background section is also included in the chapter as it supplements the material provided in the first report, *5008-1*, and provides the reader critical information needed to understand and interpret the results of the Phase II research (*1*). The findings and conclusions of this chapter are included in the last chapter, which brings together all the findings and conclusions of the research—showing how they support the final recommendations offered by the research team.

BACKGROUND

Retroreflectivity is a measure of the ability of a material to reflect light back to the originating source. It is a common property of traffic signs, delineators, object markers, barricades, raised pavement markers, and pavement markings. Although retroreflectivity is an important property of many traffic materials, few transportation professionals receive formal training on the science behind retroreflectivity. A basic understanding of this knowledge is necessary to appreciate the differences in retroreflective properties between wet and dry markings and the issues associated with measuring wet and dry marking retroreflectivity.

Pavement markings are intended to perform well when new and dry, but a significant difference in the dry and wet retroreflective performance of markings is typical. When water covers a marking, there are several factors that can reduce the ability of the marking to retroreflect the incoming light. The major factors are a scattering of light due to specular reflection off the water's surface and the change in refraction of light due to the light rays passing through an additional medium (water) with a different refractive index (RI) from that of the bead and the air. The RI for water is about 1.33. In comparison, most highway beads have an RI of 1.5 to 1.9 (the ideal RI for pavement marking beads is 1.913). The 1.5 RI bead is more common as beads with a lower RI are more durable and less expensive. To account for the additional refraction associated with water covering the beads, markings specifically designed for wet conditions include beads with an RI in the 2.4 to 2.5 range. The development of wet-weather marking materials is a recent trend in the transportation industry to address concern over the poor performance of markings in rainy conditions. The increased focus on wet-weather products has created a need for a standardized procedure for measuring the performance of these materials in wet conditions.

ASTM has established numerous standards and procedures for measuring the retroreflectivity of various materials using the standard 30 meter geometry. ASTM E1710-05, Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer, is the current procedure for measuring the dry retroreflectivity of pavement markings using a portable retroreflectometer (*2*). This procedure was first adopted in 1995.

As manufacturers began to market pavement marking materials specifically designed for wet-weather conditions, they needed a standard way to measure the retroreflectivity of markings when wet. In the late 1990s, an ASTM committee debated various procedures that could be used to measure wet marking retroreflectivity. As a result of the committee's activities, ASTM adopted two new procedures in 2001 for measuring marking retroreflectivity of wet markings (*3*,*4*).

ASTM E2176-01, Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (R_L) of Pavement Markings in a Standard Condition of Continuous Wetting, is a procedure where water is continuously sprayed on the marking while measuring retroreflectivity (*3*). It is intended to represent the retroreflectivity of a marking material during a rain condition and is also referred to as the “spray” method. The procedure specifies that the spray area should be a 20 ± 2 inches diameter circle, that the spray head height should be 18 ± 6 inches, and that the spray rate should be 0.8 ± 0.2 L/min. This spray rate equates to a rainfall rate of about 9.32 in/hr. However, the tolerances associated with various aspects of this standard procedure can result in a rainfall rate anywhere in the range of 5.78 to 14.39 in/hr (5). ASTM E2176 indicates that the rate of spray may influence the results of the measurements, but a note in the procedure states that the effects of changes in spray rate, height, and area are minimal. These statements conflict with each other, and the procedure provides no support for the accuracy of either statement. After initiating the spray condition, the user should wait 10–15 seconds before taking measurements. Readings should be taken about every 10 seconds until a steady state is achieved, which usually takes about 30 seconds. These aspects of the ASTM procedure imply that each continuous wetting retroreflectivity value will take 45 seconds or more of spraying to get one measured value.

ASTM E2177-01, Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (R_L) of Pavement Markings in a Standard Condition of Wetness, is a procedure that measures marking retroreflectivity after water has been poured on the marking and allowed time to drain off the marking (*4*). It is also referred to as the “recovery” or “bucket” method. It is intended to represent the retroreflectivity of a marking material after rain has stopped and the marking is still wet. It can also represent marking retroreflectivity in conditions of dew or high humidity. The procedure states that the wetness state can be created with a hand sprayer or a bucket of water. If a sprayer is used, the marking should be sprayed for 30 seconds. If a bucket is used, 2–5 L of water should be slowly poured over the marking. With either wetting procedure, the marking’s retroreflectivity is measured 45 ± 5 seconds after the spraying or pouring is completed. With this procedure, each retroreflectivity measurement requires over 1 minute of time for spraying/pouring and the recovery.

There are numerous similarities between the two standard procedures, but also some notable differences. Both are based on the 30 meter geometry defined in ASTM E1710. The sampling requirements for both are defined by the user and expected to be less than that used for dry retroreflectivity due to the unique aspects of the wet test measurements. Both also mention the problems associated with wet measurements of new markings due to release agents on new markings that cause beading of water until the markings are cleaned or worn in the field. A major difference between the two is that E2177 mentions the road incline, or cross slope, as a factor that may impact readings, whereas E2176 makes no mention of the impact of cross slope on marking measurements. As described later in this chapter, the cross slope of the marking has an important impact on the measured retroreflectivity value.

Although the standard procedures for wet markings have been in place for five years, there is little practical experience with these standards. Therefore, a portion of the research was intended to assess the effectiveness of the E2176 and E2177 methods and to identify critical aspects of each that should be considered for change or taken into consideration by the user when measuring the wet retroreflectivity of pavement markings. The researchers set out to understand how the retroreflectivity measurements resulting from the standard procedures correlate with performance as measured using detection distance as the measure of effectiveness.

In doing so, the researchers also progressed toward Phase II of the visibility study in which pavement markings were evaluated under both dry and wet conditions. The analyses addressed many of the key issues including correlations between dry retroreflectivity measurements and dry detection distances as well as wet retroreflectivity measurements and wet detection distances.

STUDY DESIGN

The researchers collected additional retroreflectivity measurements and a second round of detection distances during Phase II data collection (November and December 2005). The procedures were similar to those used in Phase I data collection conducted in June 2005 (*1*). However, an upgrade to the rain tunnel was completed after collecting the Phase I data but before initiating the Phase II data collection. The upgrade was designed to increase the lateral rain coverage across the roadway. In order to accomplish this upgrade, the height of the nozzles was increased and further cantilevered over the travel lane. Stiffeners were added to support this modification. The remainder of this section describes changes that were made to the study procedures for Phase II.

Selection of Study Variables

During Phase I of the study, all of the pavement marking samples were tested in simulated rainfall conditions, which allowed the researchers to make comparisons of the wet-night performance of the various marking materials. For Phase II data collection, the study conditions were broadened to include dry-night conditions, as well as to investigate the effect of headlight glare on pavement marking visibility.

Dependent Variable

As was the case in Phase I data collection, the measure of effectiveness chosen for analysis was maximum detection distance of an isolated skipline.

Independent Variables

To keep the scope of the investigation within the resources of the project, and to obtain a sample of sufficient size for analysis, the researchers identified and tested the following independent variables:

- Pavement marking materials and widths – in response to feedback from the project monitoring committee, the researchers obtained and tested more pavement marking material samples. A detailed list of all tested materials is provided in Table 1. Appendix A provides additional information as well as an image of each marking. Given the number of new materials to be tested and the desire to test more wider-line samples (6 inches), only white marking samples were included in the second round of data collection.
- Rainfall rate – The rain tunnel was again used to provide simulated rain for the experiment. However, only the high (0.87 in./hr) and low (0.28 in./hr) flow rates were used. In addition, only half of the test runs were conducted in wet conditions, with the other half of the runs conducted without simulated rainfall (dry).
- Headlight glare – During Phase I data collection, the research participants were not provided with any light besides the test vehicle's headlights and a minimal amount of ambient light from surrounding buildings. During Phase II data collection, a device simulating the appearance of opposing vehicles' headlights was introduced. Half of the test runs were conducted with the simulated headlight glare.
- Driver age – Two age categories were selected for this project: a younger group consisting of participants under the age of 55 years, and an older group made up of participants 55 years and older.

- Visual acuity – Two visual acuity categories were selected for this project: a group with visual acuity of at least 20/20 or better, and a group with visual acuity of 20/25 to 20/40.

Table 1. Pavement Marking Treatment Description.

Panel Code	Binder			Bead Type	Application
	Type	Width (inches)	Thickness (mil)		
8	Polyurea	4	17	GloMarc 90 and Type 2	Flatline with cluster beads
11	Thermoplastic	4	110	Type I, III, High Index	Structured (splatter pattern)
12	Thermoplastic	6	110	Type I, III, High Index	Structured (splatter pattern)
13	MMA[1]	6	110	Type I	Structured (splatter pattern, Duraset Pathfinder)
14	MMA[1]	4	160	Type I	Structured (splatter pattern, Duraset Pathfinder)
17	Tape 380WR	4	20	High Index	Tape
19	Thermoplastic	4	320	Mixed	Structured (diamond pattern)
20	MMA[1]	6	160	Mixed	Structured (splatter pattern, Duraset Pathfinder)
24	Tape 380WR	6	20	High Index	Tape
34	Thermoplastic	4	60	Type II	Flatline
35	Thermoplastic	4	60	Type II	Structured (rumble stripe, 24-inch spacing)
37	Thermoplastic	6	50	Type II	Flatline
38	Thermoplastic	4	70	Type II	Flatline
39	Thermoplastic	4	70	Type III	Flatline
40	Thermoplastic	6	60	Type III	Flatline
41	Thermoplastic	4	70	Type III	Structured (rumble stripe, 24-inch spacing)
42	Thermoplastic	4	70	Type III	Structured (rumble stripe, 12-inch spacing)
43	Thermoplastic	4	260	Type I, III	Structured (inverted profile, GulfLine)

[1] Indicates methyl methacrylate, which is a two part binder (plural component).

Fixed Factors

The factors that were held constant throughout the experiment include:

- Pavement marking position – All of the pavement markings of interest used for the analysis were positioned in the center of the travel lane. This center position allowed detection distance to be collected in both directions of travel as the illuminance on the markings would be the same. Distracter pavement markings were offset outside of the travel lane, but their detection distances were not measured or used in the analysis.

- Seat position – All the detection distances were recorded with the research participants driving the test vehicle and therefore from the driver's seat position.
- Vehicle speed – Each trial was performed at a cruise control set speed of 30 mph.
- Ambient lighting – The project was performed at Texas A&M University's Riverside Campus. This campus is an old Air Force Base that was donated to the University. It is approximately 12 miles from the main campus and is located in a dark, rural environment. There is little lighting from buildings or nearby communities.

Measured Factors

- Retroreflectivity – The dry, continuous wetting, and wet recovery retroreflectivity measurements were recorded for each pavement marking sample before the study began. All retroreflectivity measurements were conducted in accordance to ASTM specifications. The values were re-measured for any marking sample that had already been used in the first round of data collection. Each sample's retroreflectivity was measured using an LTL-X handheld retroreflectometer. To obtain wet retroreflectivity observations, a nozzle was suspended over the samples to provide the proper amount of continuous rainfall.
- Visual acuity – Each of the test research participants was required to have a valid driver's license. The researchers measured the static photopic visual acuity of each participant using the Snellen visual acuity chart.

Test Equipment

Test Vehicles

Three state-owned vehicles were used to conduct the test runs on the closed test course. The first vehicle was a 2004 Ford Taurus, and the second a 2001 Ford Taurus. Both vehicles were sedans with tungsten HB5-halogen headlamps that were only operated using the low beam setting. A researcher sat in the passenger seat during the test runs to collect data. The vehicle was equipped with (1) a special control switch on the passenger side that allowed the researcher to control the windshield wipers, and (2) a distance measuring instrument (DMI) for recording detection distances of the pavement marking samples (see Figure 1). During the test runs, the low wiper setting was used for the low rainfall flow rate, and the high setting was used for the high rainfall flow rates. In addition, the second vehicle was equipped with a small device that simulated the glare from an opposing vehicle's headlights. The glare source consisted of two small light bulbs and a mounting frame that was attached to the vehicle's hood. The glare source was positioned to simulate an oncoming vehicle 160 feet (~50 meters) away in the adjacent lane of a rural two-lane two-way undivided roadway (see Figure 2). The vehicle with the glare source was the lead vehicle in the study, so the lights on the back of the vehicle were blacked out so that they would not distract the driver of the vehicle that followed the glare car through the rain tunnel (see Figure 2). The lead vehicle was allowed to pass through the rain tunnel far enough to not influence the second vehicle before the second vehicle proceeded through. The third vehicle was a pickup truck that was used to deploy and retrieve the pavement marking samples between each test run. Figure 3 contains a picture of the box used to store the various samples that were kept in the bed of the truck.

Glare Source Power, DMI, Data Sheet, and Radio

Wiper Switch

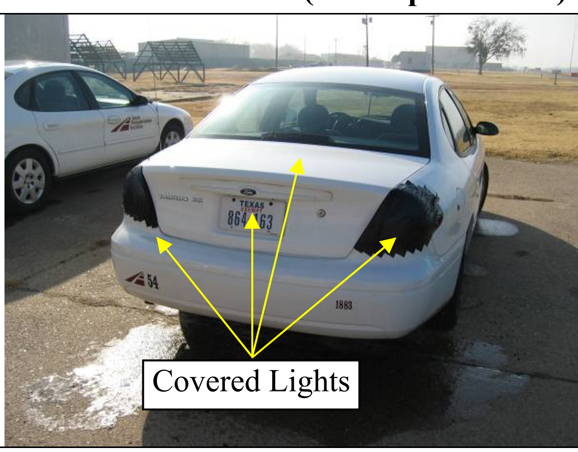
Figure 1. Standard Testing Equipment.

Glare Source (far outside view)

Glare Source (inside driver view)

Glare Source (close-up side view)

Glare Source (close-up front view)



Blacked-Out Lights (far view)

Blacked-Out Lights (close-up view)

Figure 2. Glare Source and Blacked-Out Lighting.

Figure 3. Test Sample Storage Box.

Test Course and Rain Tunnel

The same closed test course, a road on Texas A&M University's Riverside Campus, was used for Phase II data collection. A detailed description of the rain tunnel's design is provided in the *5008-1* report (*1*). A few modifications were made to improve the quality of the simulated rain and the test course's appearance. Specifically, the risers were heightened and extended so the nozzles would be suspended closer to the centerline of the road. Figure 4 contains a picture of the original riser setup and the modified riser setup. The blue raised retroreflective pavement markers (RRPMs) were also extended farther south at the southern end of the test course to allow Location A to be used for northbound dry test runs. See Figure 5 for the five test locations (A, B, C, D, and E) and the four distracter locations (F1, F2, F3, and F4).

Phase I Risers | **Phase II Risers**

Figure 4. Riser Modifications.

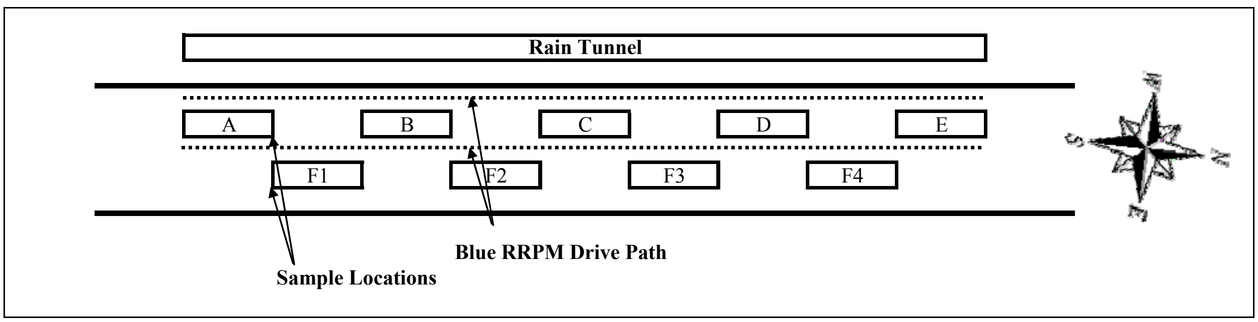


Figure 5. Pavement Marking Sample Locations.

Study Procedure

The researchers implemented the following changes to the study procedure for the second round of data collection:

- Since there are more night hours available during the winter months, data collection began by 6:00 p.m. most nights. This allowed more data to be collected on each night.
- Two test vehicles were driven through the course during each test run. The vehicle with the glare source went first, and the vehicle without the glare source followed after the first vehicle had traveled far enough (approximately 15 seconds during rain conditions and approximately 25 seconds during dry conditions) through the course that it was no longer visible from the second vehicle.

- Between test runs, while the field crew was switching the pavement marking samples, the two test vehicles lined up single-file, facing away from the test course. The tail lights of the first vehicle were blacked out, as mentioned previously, to minimize distraction and the possible glare for the research participant driving the second vehicle. In addition, the research participant in the second vehicle was instructed to turn the vehicle's headlights off while the vehicles were lined up. This was necessary because both of the test vehicles were white, and the light from the second car's headlights would otherwise reflect off the back of the first vehicle and back to the experimental subject's eyes.
- The research participants completed a total of 18 test runs each night—nine with the glare source, and nine without. After the first nine runs, the research participants and their accompanying researchers traded vehicles. The participants were then allotted a five-minute period to acclimate to the new lighting environment before proceeding with the next test run.
- Each participant reported to the Riverside Campus on two different nights—one night for all 18 wet test runs, and another night for all 18 dry test runs. To balance the study, half of the participants viewed the wet condition first, and half viewed the dry condition first. The participants were compensated $30 for the first night and $50 for the second night.
- Only detection distances were recorded by the researchers. The research participants were not asked to indicate when they recognized the pavement marking samples, as they were during Phase I data collection in June 2005. The recognition distance data collected during Phase I data collection did not yield useful information.

The researchers determined the marking setups by randomly generating them before the test runs were conducted. The material codes and deployment locations were recorded into a spreadsheet, along with the observed detection distance locations from the DMI. The actual detection distance each participant saw the marking was then calculated based on the recorded DMI locations where the participant saw the marking and the known distances to each deployment location.

Data Collection

The researchers collected the following three sets of data for this project:

- pavement marking sample retroreflectivity values under dry, wet, and recovery conditions;
- research participant information, including age, sex, Snellen visual acuity, and color blindness testing; and
- detection distances for the marking samples.

Pavement Marking Retroreflectivity

The procedures described in the *5008-1* report were used to measure dry, recovery, and wet retroreflectivity values for each pavement marking sample (*1*). A total of 14 retroreflective measurements were made (dry, recovery, and 12 continuous wetting conditions) for each marking. The retroreflectivity values of any samples that were re-used from the first round of data collection were measured again. Due to the passage of time, the researchers desired to ensure that the retroreflectivity values for these pavement marking samples were still accurate.

To provide consistent data collection, the researchers fabricated a continuous wetting spray setup as shown in Figure 6. The setup consisted of an aluminum shield to prevent water from getting on the retroreflectometer and on the retroreflectometers window located near the bottom of the unit. The setup also included a spray nozzle mounted on a tripod to provide a consistent height and location of water spray. Water was supplied to the system through a garden hose to always provide adequate water output so that system pressures were not an issue. The spray fell over a sufficiently large area for measuring the samples. Water flow rates were controlled with a flow meter that was used to adjust the continuous wetting rainfall rates applied to the pavement markings. Retroreflectivity measurements were conducted in an indoor environment so that wind was not an issue. This setup produced rainfall intensities of 1.2, 2.0, 4.0, 6.0, 8.0, 9.5, 11.5, 14.0 in/hr, and a flooding condition. These levels cover the range suggested by E2176 (6–14 in/hr) as well as rainfall rates higher and lower than this range. The lowest rainfall rate was the lowest possible rate that could be consistently produced by the spray setup, and the highest rate was not consistently measurable as it was over 20 inches per hour and thus deemed flooding.

Figure 6. Continuous Wetting Setup for Spray Conditions (Rain > 1 in/hr).

For rainfall rates less than 1 in/hr, the researchers made the measurements in the outdoor TTI rainfall tunnel. This tunnel provided the ability to create rainfall intensities of 0.28, 0.52, 0.87 in/hr across an entire simulated traffic lane. By necessity, the rain tunnel measurements required additional shielding to protect the retroreflectometer during the measurements.

In the initial indoor setup, the marking sample was placed flat with no longitudinal or lateral slope. However, researchers found that the lack of slope on flat markings resulted in a flooded marking that significantly reduced the retroreflectivity measurement. The researchers conducted several measurements of markings with 0, 2, and 4 percent cross slopes. The slopes were measured with a digital level, and all slopes were within 0.2 percent of the indicated value. The researchers collected dry, recovery, and continuous wetting retroreflectivity measurements on four sample materials. As this was a preliminary setup prior to the formal data collection, the intensity rate for the continuous wetting condition was about 10 in/hr, which is slightly greater than the recommended rate in E2176, but well within the allowable limits. The results of this experiment (described in the results section) led the research team to use marking samples with a cross slope of 2 percent, similar to that present on a typical roadway. This cross slope drained sufficient water to provide a reasonable measure of wet marking retroreflectivity, but not so much that it represented an unrealistic condition. This also provided a degree of consistency between the indoor and outdoor markings, as the road used for the outdoor rain tunnel had a cross slope of about 2 percent.

ANALYSIS OF RETROREFLECTIVITY MEASUREMENTS

Upon completing the retroreflectivity measurements, the researchers processed the data and conducted various statistical tests to assess the relationships between the dry, recovery, and the 12 continuous wetting retroreflectivity values for the set of samples. In all, there were over 1500 recorded retroreflectivity measurement values. The analysis included an assessment of the impacts of the cross slope on the retroreflectivity measurement, identifying relationships between the measured retroreflectivity in various wetness conditions and the type of material, statistical analysis of the relationship between the retroreflectivity values and the continuous wetness rates, and the impact of the range in continuous wetting rates allowed by E2176 (*6*).

Cross Slope Impacts on Retroreflectivity Measurement

As part of the Phase II visibility study preparation, the researchers measured marking retroreflectivity for several samples with various cross slopes. Table 2 presents the results of the measurements. For all but one sample in the continuous wetting condition, an increase in the cross slope resulted in a corresponding increase in the wet retroreflectivity value. In most cases, providing a 2 percent cross slope resulted in a retroreflectivity increase of 20 percent or more over the flat marking. Providing a 4 percent cross slope increased the retroreflectivity measurement by almost 50 percent or more. Based on these results, and the knowledge that the outdoor rain tunnel had a cross slope of about 2 percent, the researchers decided to position all markings at a cross slope of 2 percent for all wet measurements.

Retroreflectivity Values as a Function of Wetness and Material Type

Figure 7 illustrates the change in retroreflectivity associated with the three ASTM measurement standards: E1710 for dry conditions, E2177 for recovery, and E2176 for continuous wetting. As can be seen in this plot, except for one sample, the continuous wetting value is less than the recovery value, and the recovery value is less than the dry value. The one sample (#16) that did not follow this trend had retroreflectivity values above 1200 $mcd/m^2/lx$ for all measurement conditions. The researchers attribute this result to the fact that the retroreflectometer operation manual indicates that the instrument's measurement range is 20–1200 mcd/m^2/lx. As a result, materials with retroreflectivity values over 1200 have greater variability in the retroreflectivity measurements. This plot clearly indicates a consistent trend in the change of retroreflectivity values associated with the three ASTM standard procedures. Though the overall trend is consistent, for each marking type the results are not as consistent, indicating that different marking types are not affected the same. This inconsistent trend across marking types can be seen because the lines are crossing; if it was consistent, the lines would be closer to parallel. This information also presents an incomplete perspective on the effects of rainfall intensity on measured retroreflectivity as only one continuous wetting rainfall rate from the range of acceptable rates was used. To better understand that relationship, the researchers considered the retroreflectivity measurements across the complete range of continuous wetting rates.

Table 2. Effects of Cross Slope on Wet Measurements.

Material, Bead (all markings are white)	Measured Retroreflectivity, R_L, (mcd/m^2/lx) for Indicated Condition and Cross Slope							Change in Retroreflectivity from 0% Cross Slope			
	Dry (E1710)	Recovery E2177)			Continuous (E2176)			Recovery		Continuous	
	0%	0%	2%	4%	0%	2%	4%	2%	4%	2%	4%
Thermo, Type III	1044	266	379	425	28	66	90	42.5%	59.8%	135.7%	221.4%
Structured Tape	943	604	620	624	88	218	258	2.6%	3.3%	147.7%	193.2%
Thermo, Mixed	825	104	125	152	32	43	52	20.2%	46.2%	34.4%	62.5%
Thermo, Type II	447	36	48	57	19	19	18	33.3%	58.3%	0.0%	-5.3%

Note: Dry and continuous wetting values are an average of six measurements, recovery values are an average of four measurements.

Table 3 presents the mean retroreflectivity values for the samples for each of the 14 measurement conditions. The table also provides information about the material binder, beads, and color. The samples are arranged in rank order according to the dry retroreflectivity value. As can be seen in this table, the retroreflectivity values among all products and measurement conditions ranged from a high of 1234 to a low of 12 mcd/m^2/lx. Once the data in the table were organized, the research team looked at various options for organizing the results for the 18 marking samples. They evaluated groupings based on binder type, marking structure, bead characteristics, and retroreflectivity characteristics. The grouping that appeared to provide the greatest distinction is one based on the retroreflectivity values. Figure 8 presents the retroreflectivity values as a function of wetting rates between 0.28 and 20.0 (flood) in/hr. Figure 8a includes the three materials for which the wet retroreflectivity values were greater than 300 mcd/m^2/lx. All three of these materials are tape products that are specifically designed for wet-weather conditions. Figure 8b presents the materials with wet retroreflectivity values less than 300 mcd/m^2/lx. A review of these plots reveals that almost all materials have noticeable changes in retroreflectivity as the wetting rate increases. In many cases, the change is substantial. The statistical significance of the changes in retroreflectivity is addressed later.

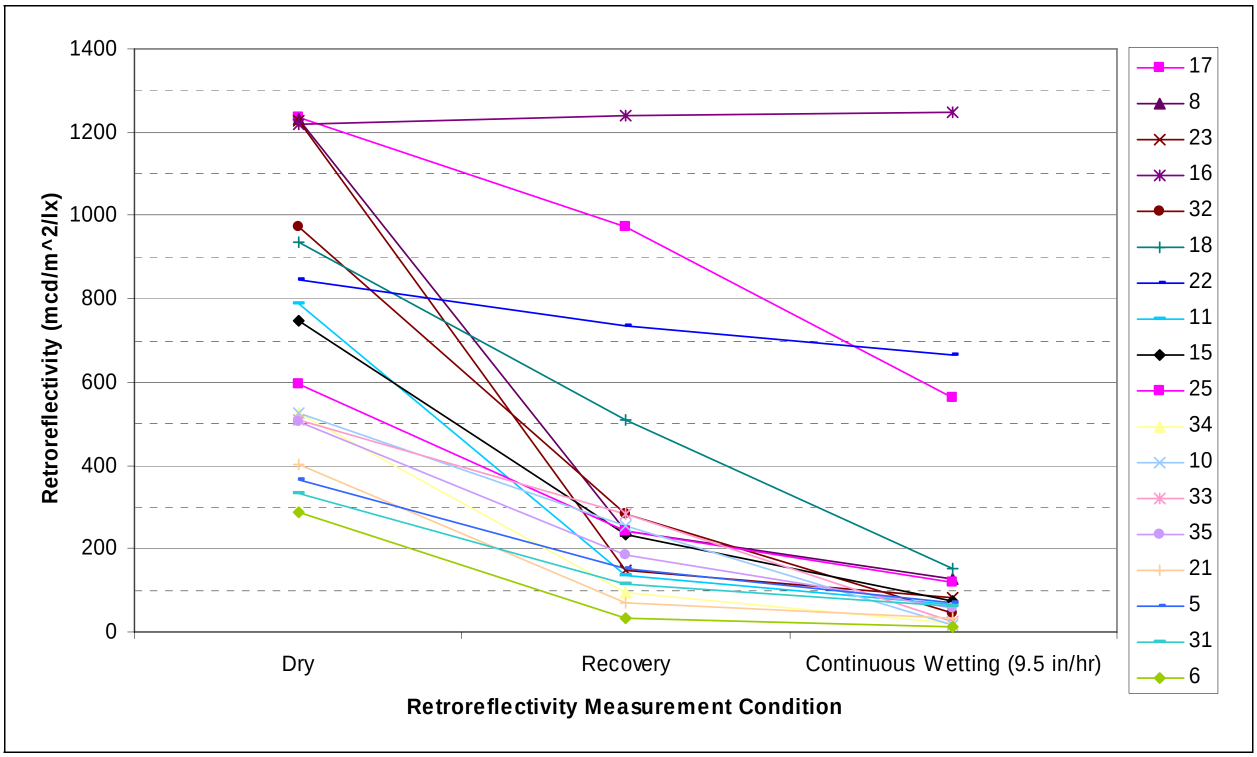
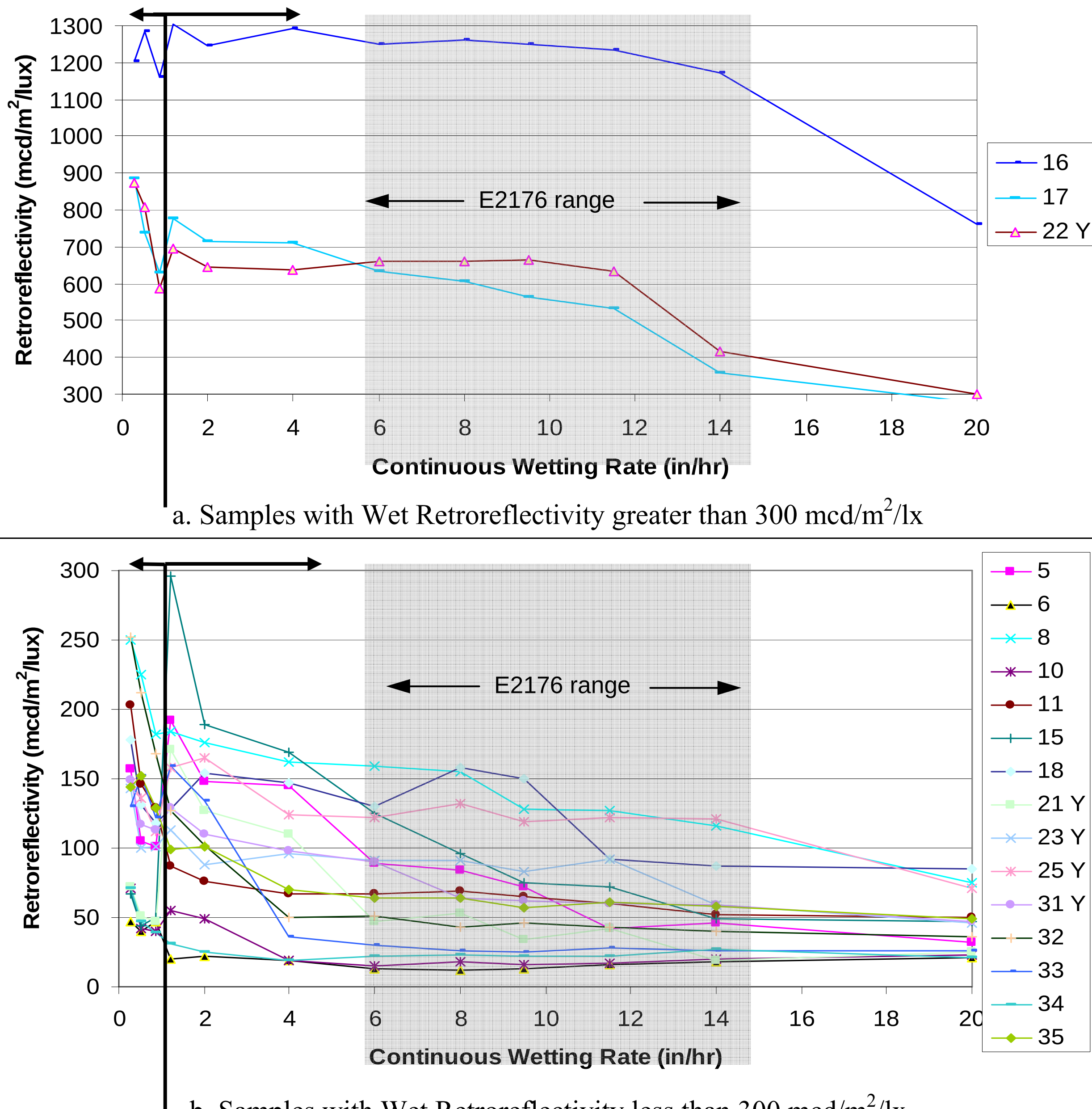


Figure 7. Change in Retroreflectivity for Various Measurement Conditions.

Table 3. Mean Marking Retroreflectivity Values for Various Wetness Conditions.

Sample	Material, Bead, Color	Measured Retroreflectivity, R_L, ($mcd/m^2/lx$) for Indicated Rainfall Rate (in/hr)													
		Dry E1710	Recov. E2177	0.28	0.52	0.87	1.2	2.0	4.0	6.0	8.0	9.5 E2176	11.5	14.0	20.0 Flood
17	Structured Wet Tape, N/A W	1234	975	887	737	631	776	716	710	634	606	564	532	359	278
8	Polyurea, Cluster Bead, W	1232	243	250	225	182	184	176	162	159	155	128	127	116	75
23	Polyurea, Cluster Bead, Y	1229	150	143	101	101	114	88	97	92	91	84	93	59	46
16	Enclosed Lens Tape, N/A, W	1220	1240	1205	1284	1161	1302	1247	1291	1251	1263	1250	1235	1173	760
32	Thermo, Type III, W	972	282	252	212	168	128	102	50	51	43	46	43	40	36
18	Standard Tape, N/A, W	937	509	178	131	118	128	154	148	130	158	150	92	88	85
22	Enclosed Lens Tape, N/A, Y	844	737	874	809	588	696	644	638	660	662	666	634	416	302
11	Thermo, Mixed, W	787	134	203	146	129	87	76	67	67	69	65	60	52	50
15	Structured Tape, N/A, W	746	232	67	44	50	296	190	169	125	96	75	72	49	48
25	Standard Tape, N/A, Y	596	243	147	136	112	158	165	124	123	133	120	122	121	71
34	Thermo, Type II, W	524	96	71	47	39	31	25	19	22	23	22	22	27	21
10	Epoxy, Type III, W	524	253	72	43	40	55	49	19	16	18	16	17	20	24
33	Thermo, Mixed, W	510	283	130	152	122	159	135	36	30	26	25	28	26	26
35	Thermo Rumble, Type II, W	503	185	144	152	129	99	101	70	64	64	57	61	58	49
21	Structured Tape, N/A, Y	401	71	73	52	47	171	127	111	47	53	34	42	20	25
5	Paint, Type III, W	364	150	157	105	101	192	148	145	89	84	72	42	46	32
31	Methacrylate, Type III, Y	334	113	149	117	114	129	110	99	90	64	62	60	59	47
6	Paint, Type II, W	288	35	48	40	47	20	22	19	13	12	13	16	18	21

Notes: Each value is an average of 6 individual measurements.
Continuous wetting measurements were made after the retroreflectivity values had stabilized.
Continuous wetting intensities < 1 in/hr were measured using the outdoor rain tunnel.
Continuous wetting intensities > 1 in/hr were measured using the indoor spray setup.



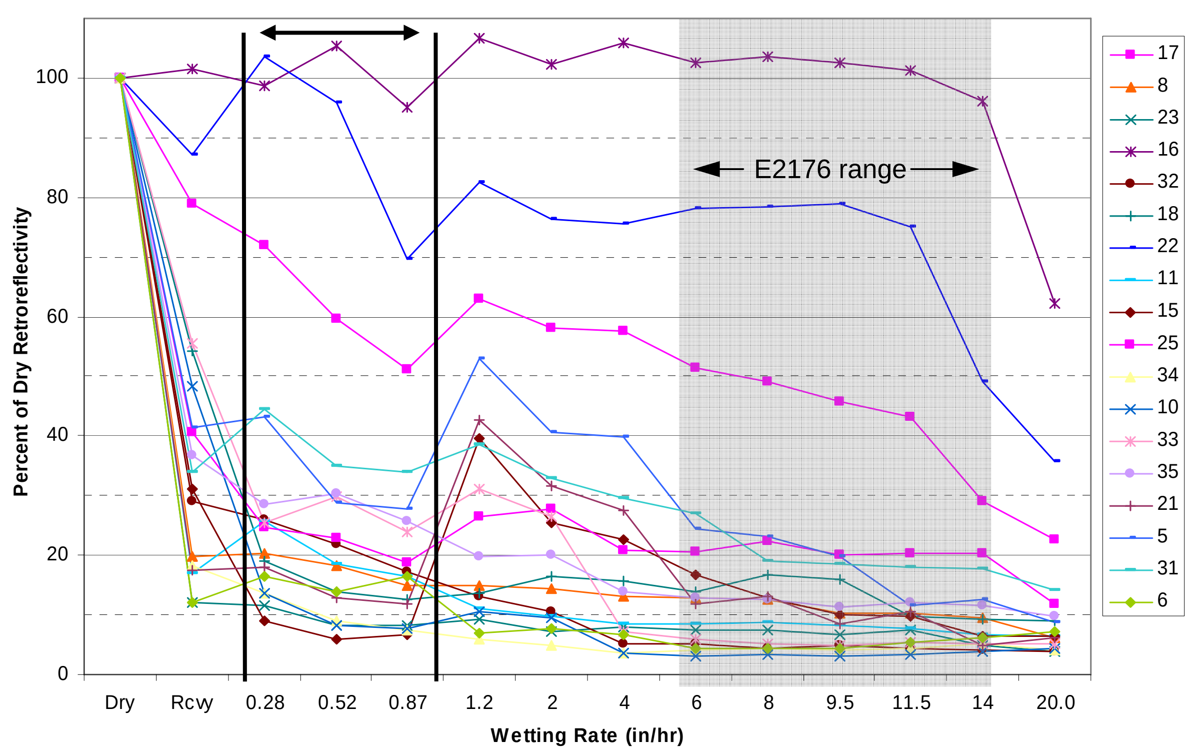
a. Samples with Wet Retroreflectivity greater than 300 mcd/m^2/lx

b. Samples with Wet Retroreflectivity less than 300 mcd/m^2/lx

Note: Values to the left of the vertical bar are values measured at the rain tunnel; values to the right were measured in the laboratory condition. Also note that all markings are white unless noted by a Y in the legend.

Figure 8. Effect of Continuous Wetting Rainfall Rate on Retroreflectivity.

To better understand the change in retroreflectivity as a function of the wetness condition, the researchers also calculated the wet retroreflectivity values as a percentage of the dry value. Figure 9 illustrates this relationship. A review of this plot clearly indicates the change in retroreflectivity values associated with the different continuous wetting rainfall techniques for some of the samples. As mentioned previously, rainfall levels less than 1 in/hr were measured in the outdoor rain tunnel, where water was falling from an elevation of approximately 15 ft with overlapping spray heads. Rainfall levels greater than 1 in/hr were measured using the indoor spray setup illustrated in Figure 6. The results illustrated in this figure indicate a clear discrepancy between conditions that are more representative of rain conditions from those that are more conducive to ease of measurement. This inconsistency in retroreflectivity measurements between 0.28 and 1.2 in/hr is also apparent in Figure 8. The spray setup at 1.2 in/hr typically produced a higher retroreflectivity value than the rainfall setup at 0.87 in/hr. Furthermore, there was not a smooth transition between the setups. This result would indicate that not all measuring systems are equal. The spray setup had as many variables as possible controlled; whereas the measurements at the rainmaker, which more closely represent field conditions, were subject to much more variability. The rainmaker measurements had a greater variability in droplet size, wind effects, increased chance of water getting on the measurement window, and increased variability in flow rates.



Note: Values between the vertical bars are values measured at the rain tunnel

Figure 9. Retroreflectivity Retention as Percentage of Dry.

Impact of E2176 Continuous Wetting Range on Retroreflectivity Measurements

Figure 10 presents the change in retroreflectivity values as a function of the rainfall intensities that are within the range permitted in E2176 (6-14 in/hr). As can be seen in this figure, the general trend is for the retroreflectivity values to decrease as the rainfall intensity increases, but there are several cases where the retroreflectivity values at a given intensity are higher than the retroreflectivity value at lower rainfall intensity. This discrepancy is due to several of the markings being flooded by even the lowest ASTM rainfall rate. The flooded marking displayed almost no retroreflective properties and the recorded retroreflectivity values are attributed to measurement "noise." Overall, the retroreflectivity values for the 18 samples are 10.0 percent less at a rate of 9.5 in/hr than they are at 6.0 in/hr. At a rate of 14.0 in/hr, the retroreflectivity values for the 18 samples are an average of 19.9 percent less than they are at 6.0 in/hr. After removing the markings that did not provide useful data, the retroreflectivity values for the 13 remaining samples are 12.8 percent less at a rate of 9.5 in/hr than they are at 6.0 in/hr. At a rate of 14.0 in/hr, the retroreflectivity values for the 13 samples are an average of 33.2 percent less than they are at 6.0 in/hr. This indicates both a statistical and practical significant difference in the relationship between measured retroreflectivity and the allowable range of rainfall intensities as set by E2176.

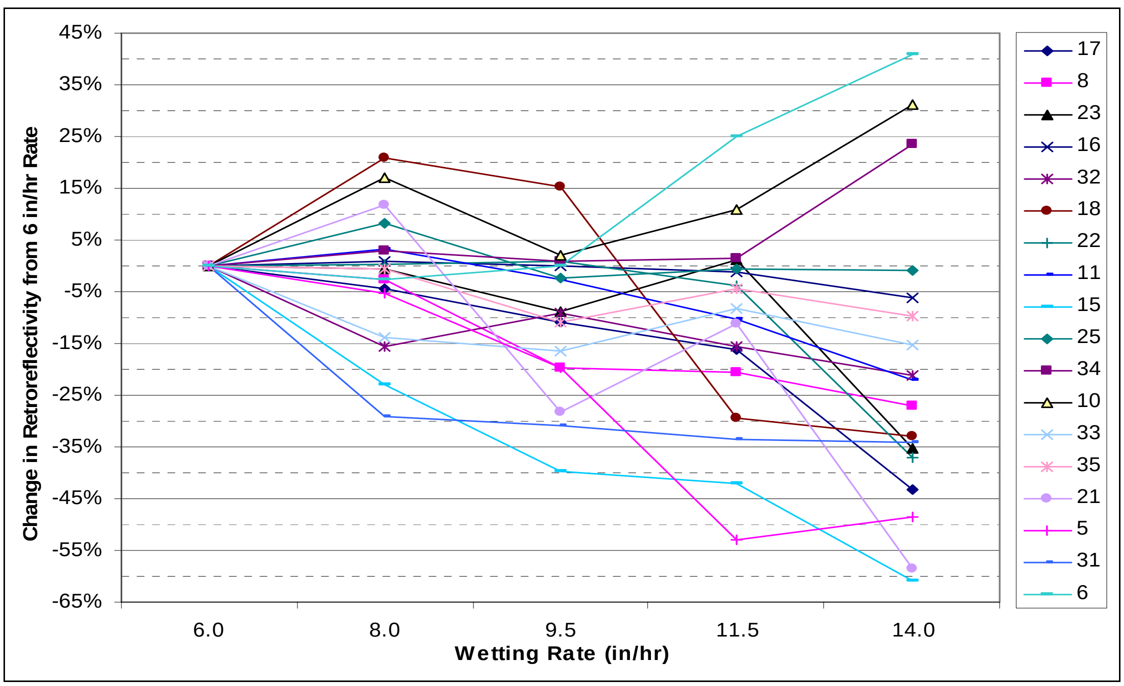


Figure 10. Change in Retroreflectivity as a Function of the ASTM E2176 Acceptable Range of Rainfall Intensities.

Statistical Analysis of Retroreflectivity-Wetting Relationship

Researchers conducted multiple two-way analysis of variances (ANOVAs) to further explore the effects of the rainfall rate on the retroreflectivity of the pavement markings. The ANOVAs compared retroreflectivity versus pavement marking and continuous wetting rainfall rate. Table 4 presents the results of the ANOVA comparing all continuous wetting rainfall rates (12 rates from 0.28 in/hr to flooding) and those that fall within the acceptable range associated with E2176 (6–14 in/hr). Both ANOVAs indicate that rainfall rate has a significant impact on retroreflectivity at α =0.05 level of significance. Researchers conducted additional ANOVAs to determine if there is a range of values that would not provide significant differences. This additional analysis did not find any range of values that proved to be insignificant.

Table 4. Two-Way ANOVA: Retroreflectivity vs. Rainfall Rate and Marking Type.

Included Rainfall Rates	Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F	P
All Continuous Wetting Rainfall Rates	Rainfall Rate	11	2662991	242090	3660.75	<0.001
	Pavement Marking	17	113395054	6670297	100864.4	<0.001
	Interaction	187	4142092	22150	334.94	<0.001
	Error	1080	71422	66		
	Total	1295	120271559		$p < 0.05$ = significant	
ASTM Continuous Wetting Rainfall Rates (6.0, 8.0, 9.5, 11.5, and 14.0 inches per hour)	Rainfall Rate	4	182110	45527	414.02	<0.001
	Pavement Marking	17	49291172	2899481	26367.17	<0.001
	Interaction	68	488945	7190	65.39	<0.001
	Error	450	49485	110		
	Total	539	50011712		$p < 0.05$ = significant	

The interpretation of the results summarized in Table 4 indicate that ASTM E2176 measurements are dependent on the rate of water falling on the markings, the type of marking being measured, and their interaction. These results begin to show hints of the weaknesses of E2176, which will be discussed in greater detail in subsequent sections.

ANALYSIS OF PAVEMENT MARKING VISIBILITY

The analyses of the detection distance data were conducted utilizing a split-plot design with Subject (driver) as a whole-plot, and each treatment combination as a split-plot. The demographic variables on subject such as Gender (2 levels: Male, Female), Age Group (2 levels: Younger, Older), and Visual Acuity serve as whole-plot factors, and the variables Pavement marking (18 levels), Glare (2 levels: On, Off), Flow (3 levels: Dry, Low, High) serve as split-plot factors. Retroreflectivity of each pavement marking was also measured as a covariate. In this study, the factor of main interest was Pavement Marking. Researchers were interested in identifying which pavement markings perform better under different conditions.

Analysis of variance tests were used to study the relationships between each of the above factors. The tests were subdivided into six analysis tasks:

1. assess the effects of pavement markings, glare, flow, age, and/or vision on detection distance;
2. assess the effect of pavement marking width on detection distances;
3. assess the effect of rumble stripe pavement marking systems on detection distance;
4. assess the effect of each study vehicle on detection distance;
5. assess the effect of pavement markings, flow, age, and/or vision on detection distance by each study vehicle; and
6. assess the relationship between detection distance and retroreflectivity.

Demographics

A total of 36 research participants completed the visibility study. A stratified random sample based on age and gender was selected from a large population of previous participants from other unrelated research studies. This research required volunteer participants, and so not all participants initially contacted chose to take part in the research. Subsequently, additional test participants were contacted based on referral from the initial pool of test participants. The final participant pool was stratified with approximately one-third older drivers, two-thirds younger drivers, and approximately one-half male and one-half female licensed drivers (see Table 5). The younger age group consisted of drivers that were 18 years of age to 54 years of age, and the older age group was comprised of drivers who were 55 years of age or older. The drivers came from various cities within approximately 60 miles of College Station, Texas.

Table 5. Research Participant Demographics.

Age Group		Under 55		55 and Older		Total by Gender
Vision Group		20/10 to 20/20	20/25 to 20/40	20/10 to 20/20	20/25 to 20/40	
Gender Group	Male	9	2	4	4	19
	Female	9	2	3	3	17
Total by Vision & Age		18	4	7	7	
Total by Age		22		14		36

Statistical Testing Using Analysis of Variance

Detection distance was the dependent, or response, variable for the analysis of variance tests. There were 2634 detection distance measurements collected throughout Phase II of this pavement marking study. For each measurement, there were at least five additional factors associated with each detection distance (DD), and they were: Pavement Marking Treatment (PMT), rainfall Flow Rate (FR), Headlight Glare (HG), Age Group (A), and Vision Group (V). The location of each marking for each recorded detection distance was also recorded, and while it was considered a variable that would not influence detection distance, the Location Code (LC) was included in some of the analyses to assess whether it did affect detection distances. Furthermore, two-way interaction effects between Pavement Marking Treatment and the other factors (i.e., PMT*FR, PMT*HG, PMT*A, PMT*V, and PMT*LC) were investigated, and it was found that only Flow Rate and Pavement Marking Treatment had a statistically significant interaction effect. Hence, it is the only two-way interaction effect that is discussed in detail throughout the analysis.

In the residual analysis, it was noted that one of the underlying assumptions for applying linear models, a constant variance assumption, was slightly violated. The residual variance showed a slightly increasing pattern as the detection distance increases, and there also seemed to be a few outliers. To stabilize the error in the variance and also to diminish the effect of outliers, a square-root transformation was applied to the response variable Detection Distance. The log-transformation was also tried initially, but it turned out that the log-transformation over-corrected the problem of increasing variance and led to a problem of decreasing variance, so it was not pursued further. The resulting response variable was denoted by SqrtDetect.

All of the analysis was completed using the JMP® statistical package. This software package is a SAS product that provides enhanced analysis capabilities. "JMP can be deployed as a standalone desktop analytical tool that accesses data stored in many formats. It integrates with other SAS products and solutions to marry JMP desktop data visualization, design of experiments, and exploratory data mining with SAS production processing" (*7*).

Effects of Pavement Markings, Glare, Flow, Age, and/or Vision on Detection Distance

Model A was the split-plot model developed with Pavement Marking Treatment, Flow Rate, Headlight Glare, Age Group, Vision Group, Location Code, and FR*PMT as factors. Vision Group and Age Group were whole-plot factors, with test subject drivers nested within these two factors. Pavement Marking Treatment, Headlight Glare, Flow Rate, Location Code, and FR*PMT were split-plot factors. Table 6 contains the analysis output obtained by the restricted maximum likelihood (REML) method implemented in the JMP statistical package. The least square mean values and the predicted distances associated with each of the levels within each study factor are listed in Table 7. The original outputs of the JMP software are recorded in Appendix B (see Table B1).

Table 6. Model A Results for PMT, HG, FR, LC, A, V, and FR*PMT.

SUMMARY OF FIT	
Statistic	**Value**
R-Square	0.7897
Adjusted R-Square	0.7845
Root Mean Square Error	1.4905
Mean of Response	14.9894 (predicted mean distance ~ 225 ft)
Number of Observations	2634

FIXED EFFECT TESTS					
Factor	**Nparm**	**DF**	**DFDen**	**F Ratio**	**Prob > F**
Pavement Marking Treatment (PMT)	17	17	2536	34.4867	**<.0001**
Headlight Glare	1	1	2539	188.4432	**<.0001**
Flow Rate (FR)	2	2	2540	1726.842	**0.0000**
Age Group	1	1	32.71	5.0016	**0.0323**
Vision Group	1	1	32.66	5.2558	**0.0285**
Location Code	8	8	2537	191.0741	**<.0001**
FR*PMT	34	34	2536	7.3298	**<.0001**

Note: Significant effects are shown in **bold.**

From Table 6, it can be seen that the effects of all of the factors are statistically significant at $\alpha = 0.05$. The effect of Glare is counter-intuitive, however, because the detection distance is longer with the glare source On. Once this finding was evident, the researchers tested the headlamp performance of the test vehicles and unfortunately learned that although the headlamps were the same in each vehicle, the intensity of headlights of the test vehicle with the glare source On was much higher than that of the test vehicle with the glare source Off.

Table 7. Model A Least Square Mean and Predicted Distance Values by Factor and Level.

Factor	Level	Least Square Mean	Predicted Distance (ft)
Pavement Marking Treatment	8	15.1231	229
	11	14.2612	203
	12	14.6306	214
	13	14.4443	209
	14	14.2426	203
	17	15.4234	238
	19	14.6168	214
	20	15.1226	229
	24	15.8447	251
	34	13.3392	178
	35	13.9727	195
	37	13.3849	179
	38	13.2834	176
	39	14.1301	200
	40	13.5681	184
	41	13.8039	191
	42	13.6697	187
	43	14.6103	213
Headlight Glare	Off	13.9016	193
	On	14.7064	216
Flow Rate	High (0.87 in/hr)	12.5908	159
	Low (0.25 in/hr)	13.5188	183
	Off (No Rain)	16.8024	282
Age Group	Older	13.7694	190
	Younger	14.8386	220
Vision Group	20/25 to 20/40	13.7242	188
	20/10 to 20/20	14.8837	222

Figure 11 contains the illuminance values for the two vehicles driven by test subjects during the Phase II data collection. There was approximately five times more light cast on the pavement marking treatments by the test vehicle with the built-in glare source as there was by the test vehicle without the glare source. Consequently, the effect of Glare is confounded with the effect of illumination/vehicles. Additional analyses of this issue are presented and described in a subsequent section called "Effects of Study Vehicle on Detection Distance."

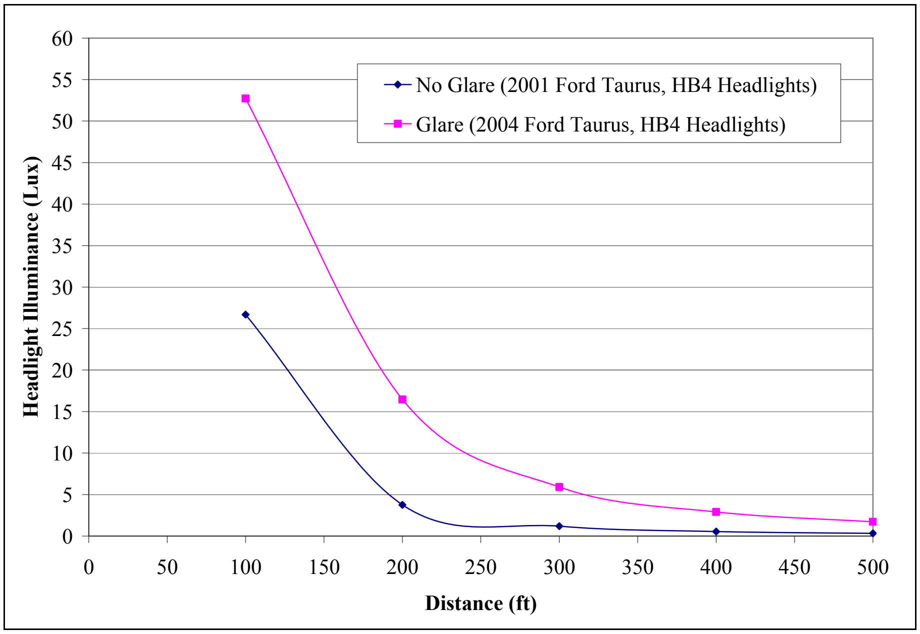


Figure 11. Difference in Headlight Illuminance between Study Vehicles.

The significant interaction effect between Pavement Marking and Flow indicates that the effect of Pavement Marking can only be assessed conditional on each level of Flow: off (O), low flow (L), and high flow (H). An interaction plot for Flow*Pavement Marking is presented in Figure 12. Note that the interaction plot is based on the least squares means for the square root of the detection distances. When there are multiple factors in the model, it is not fair to make comparisons between raw cell means in data because raw cell means do not compensate for other factors in the model. The least squares means are the predicted values of the response variable SqrtDetect for each level of a factor that have been adjusted for the other factors in the model. From Figure 12 it can be observed that the effect of Pavement Marking on SqrtDetect is different for each of the rainfall flow rate levels. Table 7 contains the predicted mean detection distance values for each of the factors in Model A.

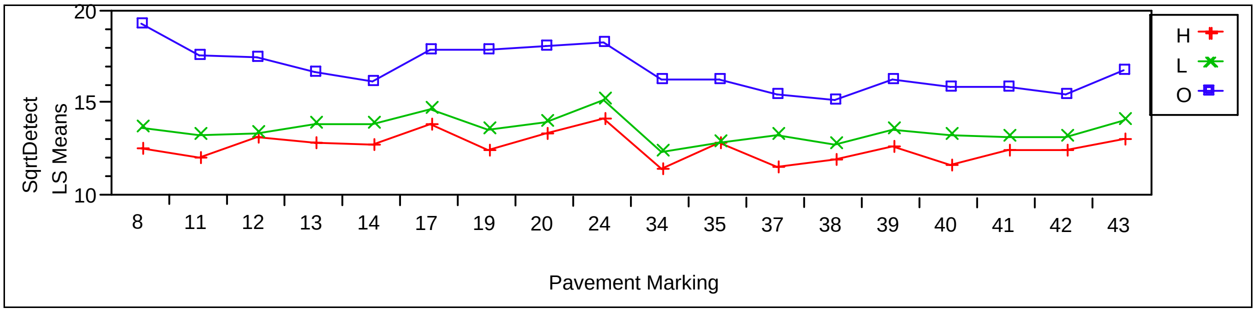


Figure 12. Interaction Plot of Flow and Pavement Marking.

The primary focus of this analysis was to investigate the performance of the various different pavement marking treatments with respect to rain; hence, an additional analysis was performed that removed the dry condition with the rainfall rate set to 0 or off. This subset of data consisted of 1434 measurements, and the new model was defined as Model A_{WET}. The results are shown in Table 8 (also see Table B2 in Appendix B).

Table 8. Model A_{wet} Results for PMT, HG, FR, LC, A, V, and FR*PMT.

SUMMARY OF FIT					
Statistic	**Value**				
R-Square	0.7074				
Adjusted R-Square	0.6980				
Root Mean Square Error	1.2460				
Mean of Response	13.2003 (predicted mean distance ~ 174 ft)				
Number of Observations	1434				
FIXED EFFECT TESTS					
Factor	**Nparm**	**DF**	**DFDen**	**F Ratio**	**Prob > F**
Pavement Marking Treatment	17	17	1357	22.8022	**<.0001**
Headlight Glare	1	1	1357	65.9842	**<.0001**
Flow Rate	1	1	1360	201.0292	**<.0001**
Age Group	1	1	31.08	2.4252	0.1295
Vision Group	1	1	31.08	3.7862	0.0608
Location Code	7	7	1358	50.9547	**<.0001**
FR*PMT	17	17	1357	1.9314	**0.0126**

Note: Significant effects are shown in **bold.**

Note that the effects of Age and Vision Group are not statistically significant anymore at $\alpha = 0.05$. The significant interaction effect between Pavement Marking and Flow again indicates that the effect of Pavement Marking needs to be assessed conditional on each level of Flow. An interaction plot for Flow*Pavement Marking is presented in Figure 13, which shows that the effect of Pavement Marking on SqrtDetect is somewhat different for Flow L and H.

A Tukey's multiple comparison test procedure was completed to investigate whether the differences between the factor levels of flow presented in Figure 13 were statistically significant. The results are displayed in Table B3 in Appendix B. There were only six products that had statistically significant differences between their high and low rainfall rate square root detection distances, and they were 11, 13, 24, 37, 40, and 43. There was not a specific trend (e.g., binder material, bead type, application type) associated with any of these markings that could describe why these were the only markings to have statistically significant differences. Some of the markings had Type I, Type II, Type III, high index (1.9), or a combination of these bead types applied to thermoplastic, methyl-methacrylate (MMA), or tape. Furthermore, the binders were applied both as flatline, structured, or tape markings.

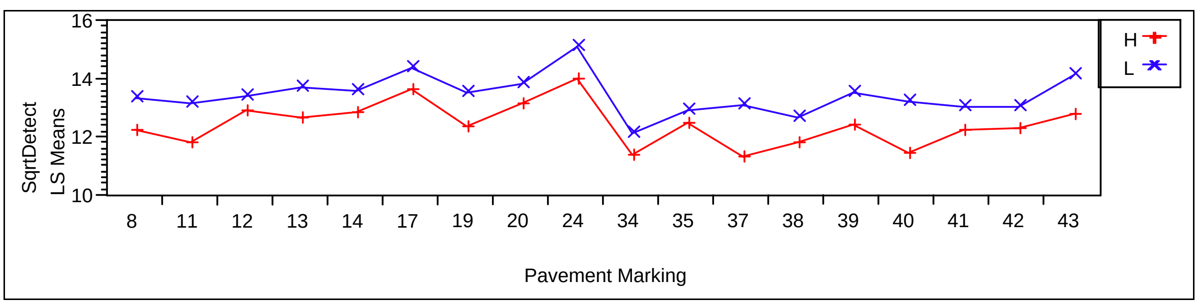


Figure 13. Interaction Plot of Flow (only High and Low) and Pavement Marking.

It should be noted that samples 17 and 24 provided the longest detection distances under both low and high rainfall rates. Sample 17 was tape applied 4-inch wide, and sample 24 was the same product just applied at 6-inch wide. The longest detection distance under both the low and high rainfall rates was sample 24 (228 ft and 195 ft, respectively). Sample 17 provided the second longest detection distance under both the low and high rainfall (206 ft and 187 ft, respectively).

These samples were also tested in Phase I of this study, and while Phase I was not set up to rigorously evaluate potential benefits of wider lines, similar results were reported. While these results appear to show some benefit of wider lines in terms of maximum detection distances, much more thorough analyses are shown in the following subsection of this report.

TxDOT typically uses thermoplastic with Type II or III beads. In comparison to the best wet condition performers summarized above, the Type III application performed reasonably well within the group of non-structured markings. The detection distances measured under both the low and high rainfall rates were 183 ft and 155 ft, respectively. The benefit of the larger Type III bead was again revealed in Phase II (as it was in Phase I) when thermoplastic with Type II beads resulted in some of the shortest detection distances, particularly under heavier rainfall rates (171 ft and 128 ft, respectively).

Effects of Pavement Marking Width on Detection Distance

Of the 18 pavement markings tested, 10 of the pavement marking treatments were paired treatments that had different pavement marking widths. The paired pavement marking treatments are listed in Table 9. It was of interest to see the effect of pavement marking width, 4-inch or 6-inch, on detection distance. The researchers investigated a variety of binder materials, application types, and bead systems.

Table 9. Pavement Marking Pairs.

Pair	Pavement Marking	Width (inches)	Binder	Application Type	Bead System
11	11 12	4 6	Thermoplastic	Structured	Mixed
13	13 14	6 4	MMA	Structured	Type I
17	17 24	4 6	Tape	Structured	High Index
37	37 38	6 4	Thermoplastic	Flat	Type II
39	39 40	4 6	Thermoplastic	Flat	Type III

Model B was a split-plot model that consisted of 784 detection distance measurements collected only under wet conditions (the rainfall flow rate was low and high). Age Group and

Vision Group were whole-plot factors (test subject was nested within Age Group and Vision Group). Headlight Glare, Flow, pavement marking Width (W), and the pavement marking Pair (P) were split-plot factors. The interaction effect Pair*Width and Location Code as a block were also included in Model B. Again, SqrtDetect was used as a response variable to cope with the problems of a non-constant variance and a slight non-normality.

The significant interaction effect between pair and width in Table 10 suggested that the effect of width will be different for each pair of pavement marking. Therefore, the analyses were conducted separately for each pair of pavement markings, but because the design of the model was the same it was referred to as the Model B_{WET}. Table 11 shows the effect of width along with the effects of other factors on SqrtDetect for each pavement marking pair (see also Table B4 through Table B14 in Appendix B). It can be concluded from Table 11 that for pavement marking pairs 11 and 17, the 6-inch marking appears to perform better than the 4-inch marking. For pavement marking pairs 13, 37, and 39, however, the 4-inch marking was not significantly different from the 6-inch marking. Furthermore, and perhaps more telling than the statistics, are the expected or predicted differences in detection distances as a function of width. The last row in Table 11 shows that the results of Model B_{wet} indicate a 16 ft maximum difference between 6-inch markings and 4-inch markings, at least in terms of maximum detection distance. For pair 39, the 4-inch marking had an average detection distance 11 ft longer than the 6-inch marking. Therefore, these results are mixed and inconclusive. However, wider pavement markings may have other benefits that the experimental design implemented in this study did not capture.

The researchers also analyzed the dry data to see if pavement marking widths significantly affected the response variable SqrtDetect. Testing the dry condition forces the Flow Rate factor to be removed from the analysis. That was the only change to Model B, so it was renamed Model B_{dry}. The results are detailed in Table 12. One thing to note is that dry detection distances are typically over 300 ft while wet detection distances are roughly half of dry detection distances.

Under the dry condition, the 6-inch pavement markings associated with pavement marking pairs 13, 17, and 37 performed better than their 4-inch pavement marking counterparts. However, pavement marking pairs 11 and 39 had longer detection distances with the 4-inch markings versus the 6-inch markings. One important factor to note here is the practicality of these findings. While they are statistically significant, the predicted differences in detection distances are on the order of magnitude of about 5 percent for any of the pairs. Similar to the analysis of pavement marking by width for wet conditions, the results here for dry conditions are mixed and inconclusive. In other words, there seems to be no systematic benefit of 6-inch wide pavement markings compared to 4-inch wide pavement markings, at least in terms of maximum detection distance (as measured in this study).

Table 10. Model B Results for HG, FR, LC, A, V, W, P, and P*W.

SUMMARY OF FIT					
Statistic	**Value**				
R-Square	0.6977				
Adjusted R-Square	0.4322				
Root Mean Square Error	1.2466				
Mean of Response	14.0147 (predicted mean distance ~ 196 ft)				
Number of Observations	784				
FIXED EFFECT TESTS					
Factor	**Nparm**	**DF**	**DFDen**	**F Ratio**	**Prob > F**
Headlight Glare	1	1	732.2	32.1031	**<.0001**
Flow Rate	1	1	734.4	148.1433	**<.0001**
Age Group	1	1	31.05	2.7864	0.1051
Vision Group	1	1	31.12	3.0989	0.0882
Width (W)	1	1	732.4	1.0165	0.3137
Pair (P)	4	4	732.4	58.9263	**<.0001**
Location Code	7	7	733.5	27.1275	**<.0001**
P*W	4	4	732.4	5.5441	**0.0002**

Note: Significant effects are shown in **bold.**

The last model that the researchers tested to investigate the effect of pavement marking width included an interaction variable, Age*Width (A*W). The goal of this test was to determine if wider lines benefited older drivers more than younger drivers. This revised model was called B_{age}. This model was first tested under wet conditions, and then retested under dry conditions. Age*Width did not have a statistically significant effect under either set of conditions with all of the P-values greater than $\alpha = 0.05$. The P-values are tabulated in Table 13. Therefore, the model containing the Age*Width interaction was not pursued further.

Table 11. Model B_{wet} Results for HG, FR, LC, A, V, and W.

SUMMARY OF FIT					
Statistic	**Value**				
	Pair 11	**Pair 13**	**Pair 17**	**Pair 37**	**Pair 39**
R-Square	0.7713	0.7818	0.8146	0.7544	0.8168
Adjusted R-Square	0.7499	0.7646	0.7998	0.7357	0.7999
Root Mean Square Error	1.317	1.0866	1.1071	1.2832	1.0831
Mean of Response	13.09	13.487	14.503	12.45	12.911
Number of Observations	141	165	164	171	143
FIXED EFFECT TESTS					
Factor	**Prob > F**				
	Pair 11	**Pair 13**	**Pair 17**	**Pair 37**	**Pair 39**
Headlight Glare	**0.0232**	**0.0002**	**0.0122**	0.5945	**0.0008**
Flow Rate	**0.0002**	**0.0001**	**<.0001**	**<.0001**	**<.0001**
Age Group	**0.0395**	**0.0413**	0.6779	0.1441	0.1510
Vision Group	0.0784	0.1886	**0.0398**	0.1351	0.0806
Width	**0.0087**	0.9873	**0.0082**	0.8303	0.0684
Location Code	**0.0047**	**<.0001**	**<.0001**	**<.0001**	**0.0152**
Predicted Difference in ft (6-inch minus 4-inch width)	**16**	**0**	**15**	**1**	**-11**

Note: Significant effects are shown in **bold.**

Table 12. Model B_{dry} Results for HG, LC, A, V, and W.

SUMMARY OF FIT					
Statistic	**Value**				
	Pair 11	**Pair 13**	**Pair 17**	**Pair 37**	**Pair 39**
R-Square	0.7901	0.8165	0.8492	0.8354	0.8539
Adjusted R-Square	0.7670	0.7997	0.8368	0.8211	0.8347
Root Mean Square Error	1.2509	1.1077	1.3381	1.1589	1.2852
Mean of Response	17.8348	16.8116	18.345	15.6993	16.6757
Number of Observations	122	144	159	152	104
FIXED EFFECT TESTS					
Factor	**Prob > F**				
	Pair 11	**Pair 13**	**Pair 17**	**Pair 37**	**Pair 39**
Headlight Glare	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0207**
Age Group	0.1606	0.1060	0.2011	**0.0234**	0.0689
Vision Group	0.7546	0.0437	0.0158	0.0887	0.3332
Width	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
Location Code	0.2689	**0.0087**	**0.0387**	**0.0235**	0.1759
Predicted Difference in ft (6-inch minus 4-inch width)	-10	**19**	**18**	**15**	-14

Note: Significant effects are shown in **bold.**

Table 13. Model B_{age} Results for HG, FR, LC, A, V, W, P, and A*W.

Pair	Pavement Marking	Width (inches)	Age*Width P-Value	
			(wet)	(dry)
11	11 12	4 6	0.4660	0.5605
13	13 14	6 4	0.6830	0.5939
17	17 24	4 6	0.3703	0.4491
37	37 38	6 4	0.9140	0.4094
39	39 40	4 6	0.1222	0.1956

Effects of Rumble Stripe Design on Detection Distance

With rumble strips being installed in many locations throughout Texas and the U.S., the researchers investigated whether a rumble stripe (installation of a pavement marking such as an edgeline or skipline over a rumble strip) would improve wet-night visibility of pavement markings (earlier research has indicated that rumble stripes may provide enhanced wet-night visibility) (*1,8*). Table 14 contains a list of three rumble stripes tested, and their flatline counterpart. The number of rumbles listed in Table 14 indicates the quantity of rumble strip grooves per linear foot of pavement marking treatment; subsequently, the "0" represents the flatline. A flatline to rumble stripe comparison was essential to test whether rumble stripes improved wet-night visibility over standard flatline markings. In addition, the three different types of rumble stripes analyzed provided researchers with the first analysis of the impact of changing rumble stripe designs. The statistical tests performed helped evaluate the three questions below. The analyses of Pairs 1 and 2 were used to answer the first question; Pair 2 was exclusively used to answer the second question, and Pair 3 was exclusively used to answer the third question.

- Can rumble stripes offer better wet-night visibility than flatlines?
- Does the spacing of rumble strips affect the wet-night visibility?
- Does the bead type affect the wet-night visibility?

Table 14. Rumble Stripe Pairs to be Analyzed.

Pair	Pavement Marking[1]	Number of Rumbles per linear foot[2]	Bead Type
1	34 35	0 0.5	II II
2	39 41 42	0 0.5 1.0	III III III
3	35 41	0.5 0.5	II III

[1] Thermoplastic was the binder material for each pavement marking treatment tested for the rumble stripe analysis.
[2] The 0.5 indicates that there was one milled rumble strip every 2 feet.

Model C was developed to study the three questions posed above, and the results from the analysis are given in Table 15 (see also Table B15 through Table B18 in Appendix B). This model uses the spacing between rumble strips as a split-plot factor.

Table 15. Model C Results for HG, FR, LC, A, V, and W.

SUMMARY OF FIT			
Statistic	**Value**		
	Pair 1	**Pair 2**	**Pair 3**
R-Square	0.6026	0.7138	0.6948
Adjusted R-Square	0.5638	0.6986	0.6737
Root Mean Square Error	1.3493	1.2508	1.2364
Mean of Response	12.5977	13.0315	12.8350
Number of Observations	136	259	186
FIXED EFFECT TESTS			
Factor	**Prob > F**		
	Pair 1	**Pair 2**	**Pair 3**
Headlight Glare	**0.0216**	**<.00001**	**.0020**
Age Group	0.0629	0.3395	**0.0108**
Vision Group	0.0616	**0.0464**	0.0605
Location Code	0.2866	**<.0001**	**0.0290**
Flow Rate	**0.0126**	**<.0001**	**<.0001**
Number of Rumble Strips	**0.0129**	0.1740	*0.9471

Note: Significant effects are shown in **bold.**
* Number of rumbles was replaced with bead type

The results from Pair 1 and Pair 2 appear to conflict at first. Pair 1 with samples 34 and 35 showed that rumble stripes do improve pavement marking wet-night visibility performance. The results for Pair 2 suggested that rumble stripes do not improve wet-night visibility. However, this conflict was explained with the finding from Pair 3. It was found that there was not a statistically significant improvement when adding Type III beads to rumble stripes in place of Type II beads (p=0.9471). Furthermore, the respective mean detection distances were similar (see Table 16). Subsequently, the results show that under wet conditions, a rumble stripe will enhance the wet-night visibility of a typical flatline pavement marking system used in Texas (thermoplastic with Type II beads). However, under wet conditions, a flatline with big beads (Type III beads) will perform better than a rumble stripe with Type II beads.

Table 16. Mean Detection Distances for Rumble Stripe Analysis.

Pavement Marking[1]	Number of Rumbles per ft	Bead Type	Mean Detection Distances (ft)		
			Dry (off)	Low	High
34	0	II	286	159	138
35	0.5	II	279	177	161
39	0	III	292	207	177
41	0.5	III	275	173	163
42	1	III	254	186	159

[1] Thermoplastic was the binder material for each pavement marking treatment tested for the rumble stripe analysis.

Effects of Study Vehicle on Detection Distance

As noted previously, the effect of Glare is counter-intuitive because of possible confounding effects between study vehicles' headlights and the glare source. To investigate this issue further, the data from the study in Phase I were combined with the data from Phase II for the pavement markings that are common to both studies: 8, 11, 17, 34, and 35. The new variable Car has values of 1, 2, or 3, for which 1 refers to the car from Phase I, 2 refers to that same car equipped with the glare source from Phase II, and 3 refers to the second car in Phase II. The researchers are interested in a comparison of Car 1 versus. Car 2 in order to try to understand the effect of the glare, and a comparison of Car 1 versus Car 3 in order to try to understand the effect of different illumination on the pavement markings.

Model D was developed using the main factors of Pavement Marking Treatment, Flow Rate, Age Group, Vision Group, Location Code, Car (C), and Retroreflectivity (R). Retroreflectivity was another new variable, and it refers to the measured retroreflectivity associated with each marking under raining conditions. The variable for the test subjects was a nested variable in the whole-plot factors Age Group and Vision Group, and the other factors were split-plot factors. The results of the analyses are detailed in Table 17 (see also Table B19 through Table B20 in Appendix B).

The results shown in Table 17 demonstrate that the effect of Car was not significant between Car 1 and Car 2, but it was significant between Car 2 and Car 3. In other words, the glare source did not affect detection distances, but the difference in headlight illumination performance between Car 2 and Car 3 did affect the detection distances. Subsequently, the earlier findings using Model A were revisited.

Table 17. Model D Results for PMT, FR, LC, A, V, C, and R.

SUMMARY OF FIT		
Statistic	**Value**	
	Car 1 & 2	**Car 2 & 3**
R-Square	0.7261	0.7217
Adjusted R-Square	0.7125	0.7075
Root Mean Square Error	1.2385	1.1968
Mean of Response	13.6269	13.3536
Number of Observations	339	330
FIXED EFFECT TESTS		
Factor	**Prob > F**	
	Car 1 & 2	**Car 2 & 3**
Age Group	0.2863	0.0889
Vision Group	**0.0445**	**0.0415**
Flow Rate	**<.0001**	**<.0001**
Retroreflectivity	0.2924	0.5619
Pavement Marking Treatment	**0.0003**	**0.0002**
Location Code	**<.0001**	**<.0001**
Car	0.1618	**0.0014**

Note: Significant effects are shown in **bold.**

Effects of Pavement Markings, Flow, Age, and/or Vision on Detection Distance by Study Vehicle

In Model A, the effects of Pavement Marking Treatment, Headlight Glare, Flow Rate, Age Group, and Vision Group were assessed based on the dataset consisting of both Car 2 and Car 3 data for all 18 pavement markings. In this section, Car 2 data and Car 3 data were analyzed separately to see if the effects of the other main factors, with the exception of Headlight Glare, were different for the different cars. Recall that Car 2 is the car equipped with the glare source in Phase II and this is the same car that was used in Phase I; Car 3 is the car without the glare source in Phase II; and the marking illuminance from the headlights for Car 2 is much stronger than that of Car 3. The model was renamed Model A′, and the results are listed in Table 18 (see also Table B21 through Table B25 in Appendix B).

The results from Table 18 show that all models performed nearly the same with R-Square levels at or just above 80 percent. In addition, under wet conditions the only difference in statistical findings is Age group, where age group was not significant for Car 2 but significant for Car 3 (note: Car 3 had about five times as much headlamp illumination reaching the pavement markings). For Car 3, the younger drivers were able to detect the markings on average 35 ft further than the older drivers. For Car 2, the difference was only 22 ft. However, for both Car 2 and Car 3, the Vision Group produced differences of about 30 ft.

Under dry conditions, the same age group phenomenon was observed. The younger test subjects were able to use the additional forward illumination more efficiently than the older drivers, causing statistically longer detection distances for this group. Note that the vision group code, based on photopic visual acuity measurements, failed to produce statistical findings for Car 3 under dry conditions. This is where the longest detection distances were found (because of the dry conditions and increased forward illumination) and where one may expect visual acuity levels to be significant. However, the researchers suspect that the visual acuity measurements made under photopic conditions begin to have less and less relevance in situations such as the testing conducted herein where visibility levels are mesopic and perhaps approaching scotopic. Visual acuity measurements made under these visibility levels may have led to more consistent findings in this analysis.

Table 18. Model A′ Results for PMT, FR, LC, A, V, and FR*PMT.

SUMMARY OF FIT				
Statistic	**Value**			
	Car 2 (Wet)	**Car 3 (Wet)**	**Car 2 (Dry)**	**Car 3 (Dry)**
R-Square	0.8023	0.8094	0.8327	0.8178
Adjusted R-Square	0.7922	0.8000	0.8244	0.8096
Root Mean Square Error	1.5160	1.3916	1.2321	1.2141
Mean of Response	15.2761	14.7099	17.5738	16.7192
Number of Observations	1300	1334	573	627
FIXED EFFECT TESTS				
Factor	**Prob > F**			
	Car 2 (Wet)	**Car 3 (Wet)**	**Car 2 (Dry)**	**Car 3 (Dry)**
Pavement Marking Treatment	**<.0001**	**<.0001**	**<.0001**	**<.0001**
Flow Rate	**<.0001**	**<.0001**		
Age Group	0.1293	**0.0125**	0.2165	**0.0178**
Vision Group	**0.0290**	**0.0367**	**0.0294**	0.0831
Location Code	**<.0001**	**<.0001**	**<.0001**	**<.0001**
FR*PMT	**<.0001**	**<.0001**		

Note: Significant effects are shown in **bold.**

Relationship between Detection Distance and Retroreflectivity

To better understand the relationship between measured retroreflectivity and pavement marking performance in terms of nighttime detection distance, the researchers conducted correlation analyses between the mean detection distances and the measured retroreflectivity levels using a semi-log scale. The researchers measured retroreflectivity of each of the pavement markings under 13 different measurement conditions (see Table 19). The researchers then tested for correlation of the retroreflectivity values under each condition with respect to the detection distances recorded from the field data collected at the rainmaker under low and high rainfall rates. The coefficient of determination, r^2, was used because it gives the proportion of the variance of one variable that is predictable from the other variable. The higher the coefficient of determination value, the more certain predictions can be. Table 19 shows results from Phase I of this study (5,9).

As expected, the dry retroreflectivity measurements had poor correlations with the wet detection distances. The recovery retroreflectivity measurements had rather low correlations as well. However, these relationships were not the primary focus of this analysis. They are reported herein only to confirm that dry and recovery retroreflectivity measurements have little correlation to marking performance under continuous wetting conditions.

Table 19. Retroreflectivity and Detection Distance Correlation Analysis Results.

Measurement Condition[1]	All 18 Pavement Markings		15 Pavement Markings	
	Low	High	Low	High
Dry	0.335	0.402	0.570	0.575
Recovery	0.532	0.575	0.422	0.392
0.28 in/hr	0.632	0.779	0.572	0.719
0.87 in/hr	0.653	0.787	0.470	0.621
1.2 in/hr	0.485	0.622	0.046	0.244
2.0 in/hr	0.549	0.630	0.228	0.267
4.0 in/hr	0.570	0.625	0.296	0.230
6.0 in/hr	0.621	0.691	0.495	0.366
8.0 in/hr	0.644	0.670	0.620	0.348
9.5 in/hr	0.679	0.708	0.690	0.403
11.5 in/hr	0.687	0.720	0.692	0.356
14.0 in/hr	0.770	0.723	0.722	0.295
Flooding (20 in/hr)	0.750	0.766	0.670	0.435

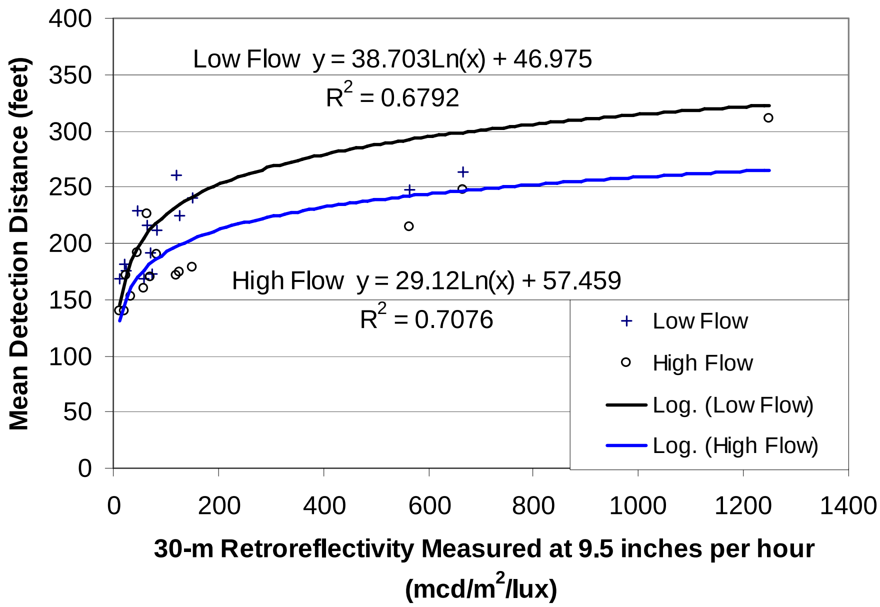
[1]The 0.28 and 0.87 in/hr measurement conditions were measured at the rainmaker, and all other measurement conditions were conducted in a lab. Also, in/hr indicates inches per hour.

The correlation analyses associated with the continuous wetting retroreflectivity measurements clearly show a positive correlation, but to varying degrees (see Table 19). When all pavement markings were considered together, the correlation is relatively strong. However, when a reduced set of pavement markings is considered, the correlation is not nearly as strong. The reduced set of pavement markings included 15 of the 18 pavement markings. The three that were removed from the second group were the three with measured retroreflectivity levels over 300 mcd/m^2/lx (using ASTM E2176 wetting rates). These three markings had retroreflectivity measurements as high as 10 times that of the other 15 pavement markings. When data such as these are included in correlation analyses, they can be very influential, leading to biased results and unrepresentative relationships for the majority of the markings. As ASTM E2176 currently is written, it should work equally well for all pavement marking groupings as there are no exemptions or limitations as to applicable pavement marking types stated in the standard.

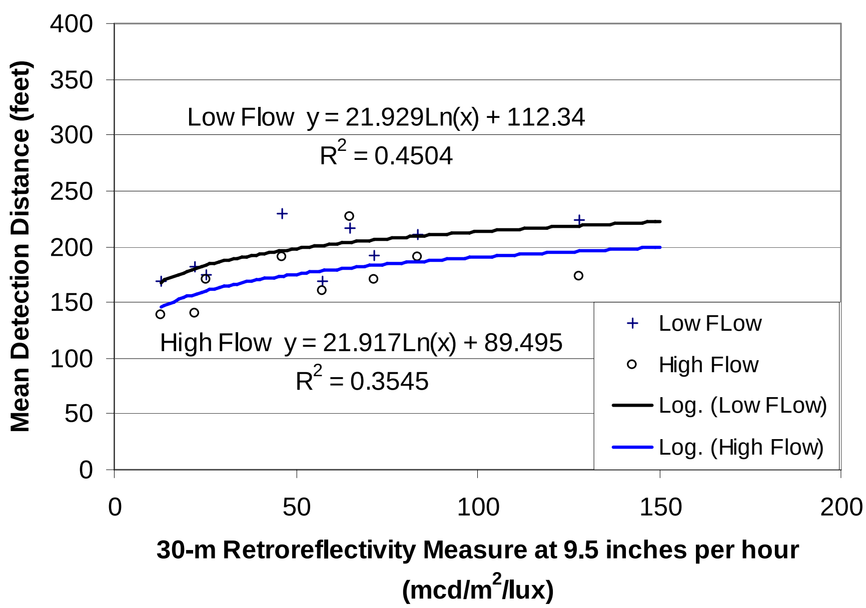
An investigation of the correlations associated with the individual rainfall rates indicates that there is not a specific continuous wetting rate that results in particularly strong correlations. Similar correlations were found even when the continuous wetting rate to measure retroreflectivity and the rainfall rate used to measure detection distance were the same. This finding can be observed with the data shown in Figure 8, which shows that the markings tested for this study do not behave similarly in any one particular range of continuous wetting rates. Additional statistical testing of the data has shown that there is no particular range of continuous wetting rates where the interaction between the continuous wetting rate and the pavement markings is not statistically significant.

Figure 14 shows an example of the relationships between detection distance and measured retroreflectivity from Phase I of the study. The data shown in Figure 14 were obtained using the ASTM standardized continuous wetting rate of 9.5 in/hr to make the retroreflectivity measurements and the average detection distances measured in the rain tunnel under typical rainfall events.

During Phase I of the study, the researchers measured all the pavement marking treatments using an MX30 handheld retroreflectometer. In Phase II, the researchers used an LTL-X handheld retroreflectometer because the MX30 has a reported ceiling of 1200 mcd/m^2/lx, and the pavement markings during dry condition were expected to have measurements above this limit. Measurements were recorded for dry and wet conditions, but all of the wet detection distances were correlated solely with retroreflectivity measurements made under the guidance of ASTM E2176, which calls for a wetting rate of approximately 9.5 in/hr. Table 20 and Figure 15 contain the measured values of retroreflectivity for each pavement marking for Phase II. As in Phase I, the retroreflectivity values for the same pavement marking are substantially different for the dry and the wet conditions.



All Pavement Markings: Mean Detection Distance and Continuous Wetting Retroreflectivity



Conventional Pavement Markings: Mean Detection Distance and Continuous Wetting Retroreflectivity

Figure 14. Relationships between Marking Retroreflectivity and Detection Distance.

Table 20. Pavement Marking Retroreflectivity In Dry and Wet Conditions.

Pavement Marking Treatment	Retroreflectivity (LTL-X)	
	Dry (ASTM 1710)	Wet (ASTM 2176)
8	1967	100
11	777	52
12	695	47
13	459	43
14	392	165
17	1011	398
19	788	85
20	675	108
24	1140	401
34	532	20
35	521	40
37	321	38
38	360	39
39	480	75
40	420	77
41	469	96
42	457	97
43	611	325

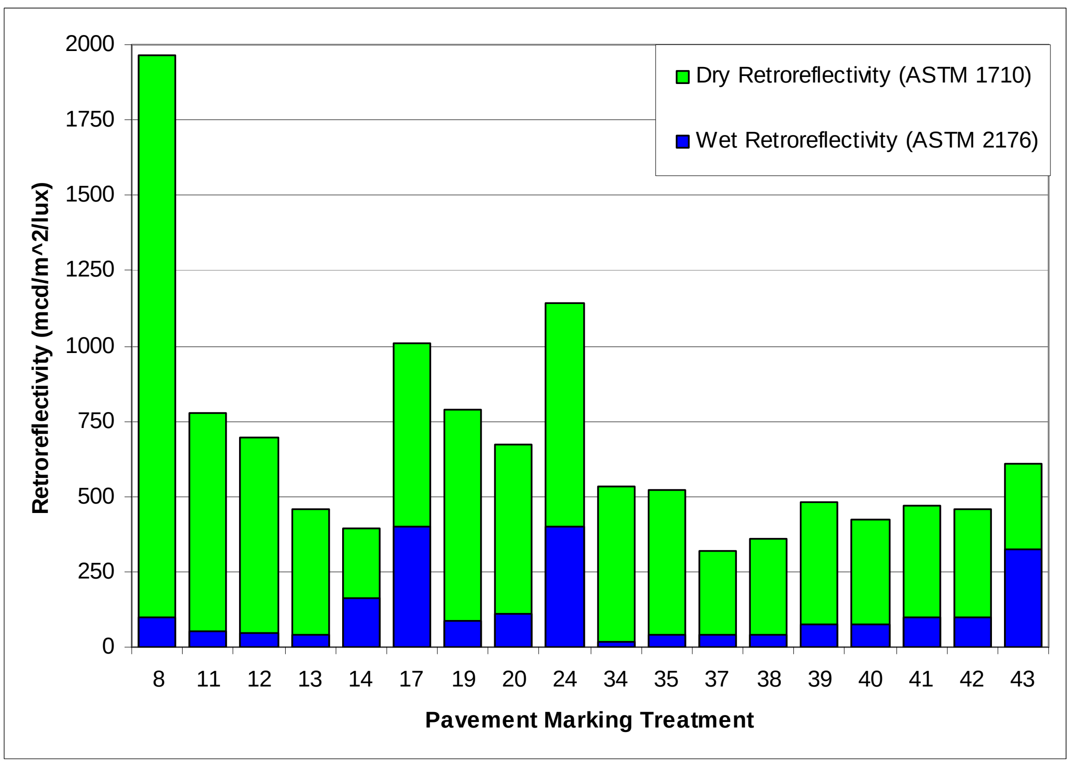


Figure 15. Pavement Marking Retroreflectivity In Dry and Wet Conditions.

In Phase II, the researchers evaluated the relationships between measured retroreflectivity and detection distances, just as reported in Phase I. The major difference is that in Phase II the researchers collected dry detection distances so that there are two sets of correlations, one for dry conditions and one for wet conditions. These results are shown graphically in Figure 16 and Figure 17.

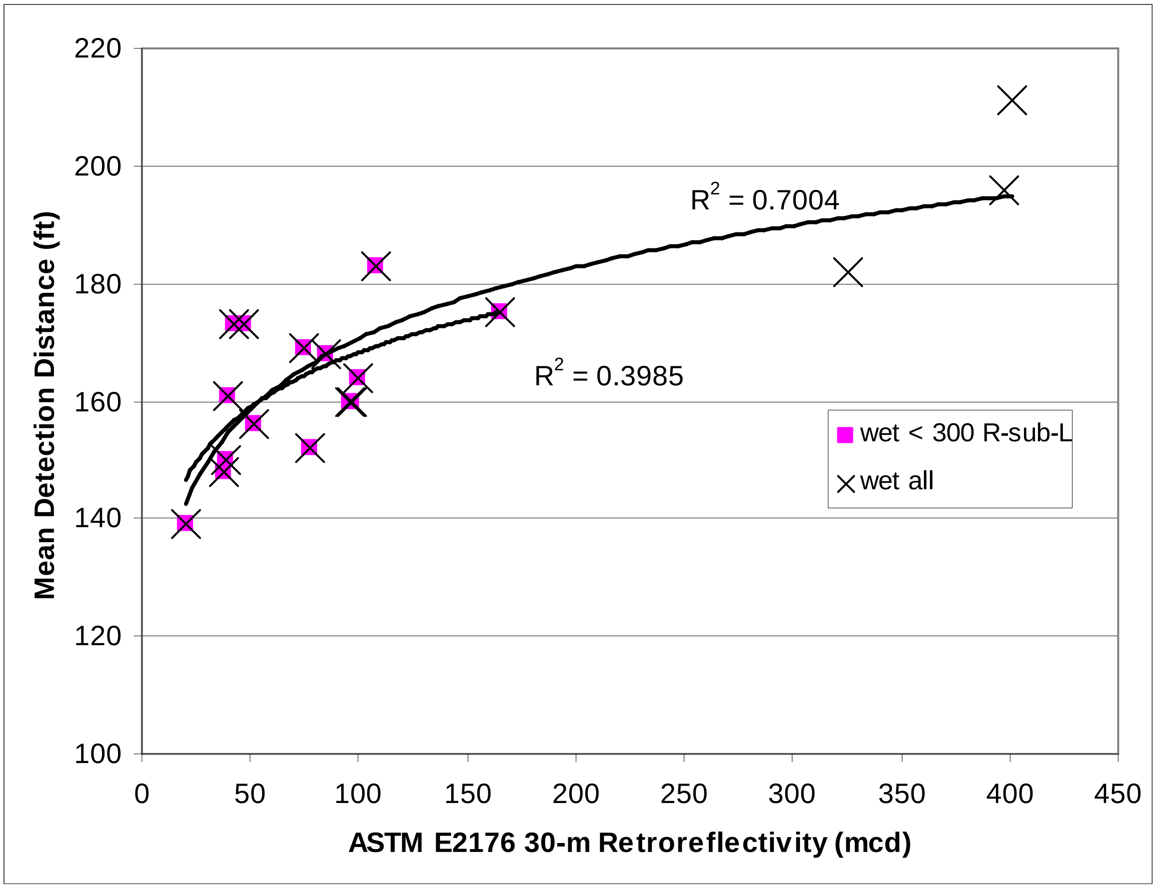


Figure 16. Phase II Correlation Results for Wet Conditions.

The findings of Figure 16 are consistent with those reported from the Phase I efforts showing reasonable correlation for all products but reduced correlation when the specially designed, seldom-used products are included in the analysis. A recent survey by Donnell et al. for the FHWA shows that 98 percent of all pavement markings from responding states are water-based or epoxy-based paints with conventional glass beads *(10)*. These marking products, and most others, are represented by the retroreflectivity levels below 300 mcd/m^2/lx, which is where the correlation between measured retroreflectivity and detection distance is poor.

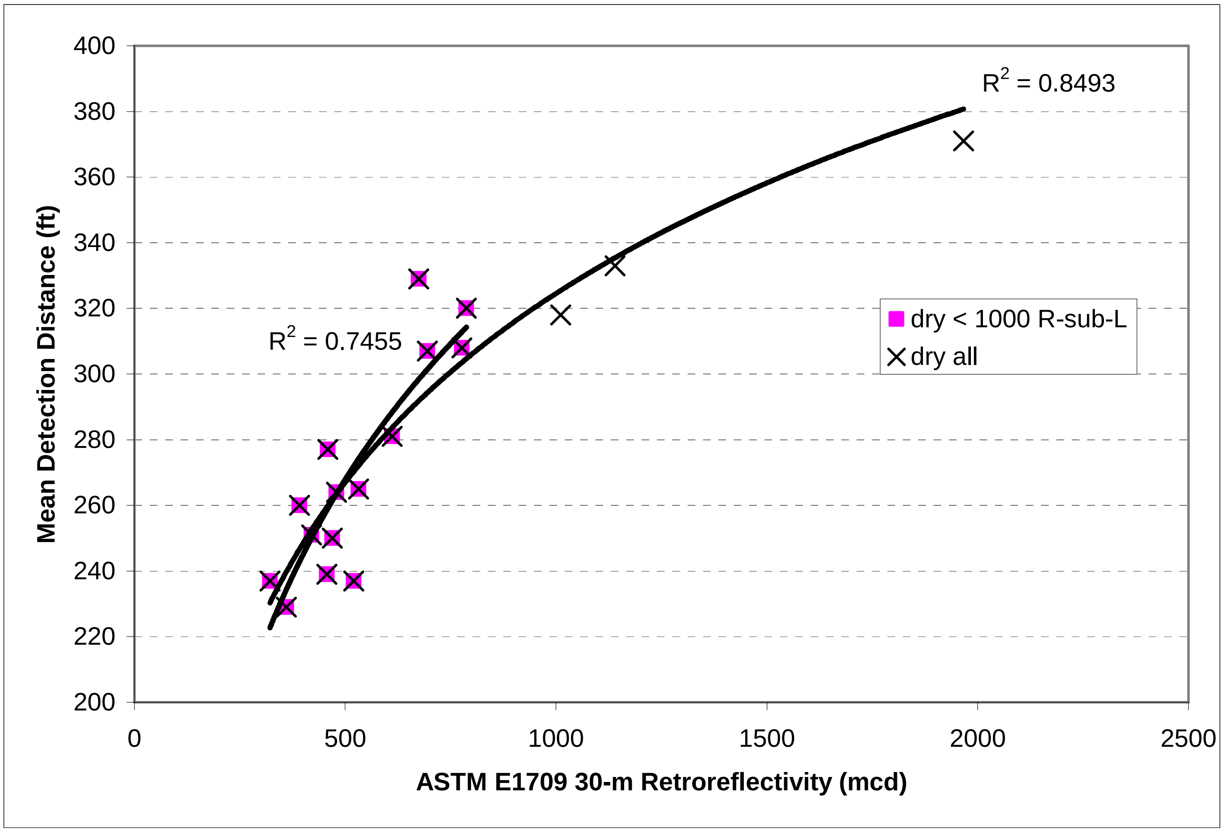


Figure 17. Phase II Correlation Results for Dry Conditions.

Figure 17 is similar to Figure 16 except that the relationship is for dry retroreflectivity measurements and dry detection distances. Here the results look much more reasonable in that correlations are reasonably strong for both subsets of markings. These findings could be used to set the benchmark for wet-night correlations if further work is performed to improve the wet measurement techniques (in terms of providing more repeatable and meaningful results).

CHAPTER 3:
BENEFIT-COST ANALYSIS

In Texas there are almost 80,000 centerline miles of state-maintained highways and roads. Pavement markings on these roads serve a key role of providing guidance and other information to drivers. With a typical one-mile stretch of two-lane undivided highway having four miles of pavement markings, the necessity to provide the most cost-effective marking is evident.

There are several aspects to achieving the most cost-effective pavement marking. The first aspect is the pavement marking cost in comparison to its service life. The second is the delay and safety aspects imposed by striping and restriping activities. The third is the quality of the marking while it is in service, i.e., during dry and wet visibility. Each of these aspects will be explored to determine the pavement markings that are the most cost-effective.

COSTS AND SERVICE LIFE

The costs and service life of a particular pavement marking will vary depending on the variables present at different locations. Some markings have particularly high costs, but this high cost is often offset by a longer service life. Other markings are much less expensive, but their service life is also shorter. Finding the balance of cost and service life is important to finding the most effective pavement marking.

Pavement Marking Costs

There are many different types of pavement markings and each of these markings has a range of costs. Geographical location, availability of materials, contract size, application type, when the striping is done, necessity of surface preparation, removal of preexisting marking material if needed, and the necessity of traffic control will all impact the installation cost of the pavement markings.

The most accessible data on current and past pavement marking costs are the TxDOT bid prices. TxDOT typically only uses thermoplastic pavement markings and thus the bid prices really only address this type of marking. Since our dry and wet-night pavement marking study included many types of pavement markings that are not widely used or are very new, other sources of cost data needed to be used. These sources included other research on pavement marking costs and direct contact with vendors, contractors, and DOTs.

Many of these sources of data contain ranges in the cost of the pavement markings. This range is an attempt to account for some of the factors that can affect the cost of the pavement markings. A typical pavement marking cost was also listed, or estimated, to try and establish a single cost for each of the marking types. Other costs associated with pavement marking installation are the costs of pavement surface preparation, elimination of existing markings, milling shoulder rumble strips, and the installation of retroreflective raised pavement markers.

Table 21 indicates the costs of the related pavement marking installation procedures. Not all pavement marking applications will incur these costs, but if necessary they will increase the cost of the marking application. Elimination of pre-existing markings typically occurs on older surfaces that have had several restripes already, on Portland cement concrete (PCC) surfaces where the previous marking is debonding, and on roads where it has been decided to use marking tape or a type of marking that will not adhere to the current marking. The milled shoulder texturing is required for the implementation of the rumble stripe and thus will be added to the cost of the standard marking to determine the cost for the rumble stripe. The RRPMs are not a pavement marking, but rather a pavement marker. RRPMs are used to supplement pavement markings by providing increased delineation, especially in wet-night conditions.

Table 21. Associated Pavement Marking Installation Costs (*11*,*12*).

Pavement Surface Preparation	\$0.05/lf
Eliminate Existing Markings	\$0.33/lf
Milled Shoulder Texturing	\$0.17/lf
RRPMs	A-A Yellow/Yellow \$3.00/each
	C-R White/Red \$3.40/each

The costs of the actual pavement markings can be found in Table 22 and Table 23. These tables are a summary of costs from nine different sources as well as personal contacts. Table 22 indicates the range of pavement marking costs that are provided by the literature. Table 23 indicates the typical costs for each of the marking materials. The researchers attempted to find costs for all of the marking types that they tested, but did not find this to be possible. For the markings where the cost could not be found, estimations were made. All pavement marking costs are in dollars per linear foot of marking. The cost of using different bead products (Type II or Type III) is not explored in this analysis. The analysis assumed a similar cost for beads since the beads are not a major part of the marking cost.

Service Life

The service life of various pavement marking systems is even more difficult to determine than the marking costs. There are many factors that can affect the service life of the marking. The traffic volume and roadway surface type are two of the major influences on the service life of pavement markings. There are also many other factors that can influence service life, including the following: percent heavy vehicles, application conditions, weather conditions, winter maintenance activities, orientation of the marking, roadway geometry, marking thickness, type of retroreflective elements used (glass beads), and criteria for determining the end of the marking life.

Based on reviewed literature, TxDOT input, and manufacturer warranties, the service life of the pavement marking materials were determined in Table 24 and Table 25. Service life of a particular marking will differ somewhat based on the previously mentioned variables. Service life listed is an estimate of typical service life of the indicated marking. Based on the actual conditions at each site, the service life could be longer or shorter, either increasing or decreasing the cost for the marking over the life of its installation.

Table 24 indicates the range in service life for the various pavement markings. It can clearly be seen that there is a large range in service life for the pavement markings. Table 25 attempts to estimate the typical value of service life for each of the pavement marking types. For the thermoplastic, it can be seen that the estimated typical value is either 2 or 4 years. This range was to account for the typically shorter service life of thermoplastic on Portland cement concrete surfaces versus on an asphalt surface. The inverted profile thermoplastic and the pavement marking tape are both warranty items, and thus the service life was set at the end of the warranty period.

Table 22. Range of Pavement Marking Costs ($/lf).

Source	Paint 4"	Thermo 4" (Flat) 100 mil	Thermo 6" (Flat) 100 mil	Thermo 4" (Splatter)	Thermo 4" (Inverted Profile)	MMA 4" (Splatter)	Tape 4"	Polyurea 4"
TTI 4150-2 (13)	0.04-0.10	0.20-0.45				2.00-3.00	2.45	0.92-1.00
PTI 2006-06 (10)	0.02-0.15	0.08-0.85		0.35-1.30	0.35-1.30	1.12-1.75	1.50-3.10	0.43-0.90
VTRC 01-R9 (14)	0.04-0.08	0.35					1.80	0.70
C1038/3524-04 (15)		0.37-1.18			0.38-1.24	0.66-1.97	1.60-3.76	
NCHRP 392 (16)	0.02-0.06	0.20-0.80				0.25-1.25	1.04-2.25	
NCHRP 306 (17)	0.02-0.20	0.08-0.85			0.35-1.30	1.12-1.75	1.50-3.10	0.90
Texas Pvt. Mrk. Handbook (18)	0.08	0.20-0.35				2.50	2.57	1.00
TxDOT Bid New (11)		0.25-0.30	0.30-0.50				2.00-2.10	
TxDOT Bid Maintenance (12)		0.14-0.22	0.27-0.35					
Other Sources			0.51	0.65-1.15	0.75	1.10	3.00	
RANGE ($)	0.02-0.20	0.08-1.18	0.27-0.51	0.35-1.30	0.35-1.30	0.25-3.00	1.04-3.76	0.43-1.00

Table 23. Typical Pavement Marking Costs ($/lf).

Source	Paint 4"	Thermo 4" (Flat) 100 mil	Thermo 6" (Flat) 100 mil	Thermo 4" (Splatter)	Thermo 4" (Inverted Profile)	MMA 4" (Splatter)	Tape 4"	Polyurea 4"
TTI 4150-2 (13)	0.10	0.20				2.60	2.60	1.00
PTI 2006-06 (10)	0.06	0.28		0.60	0.73	1.44	2.23	0.68
VTRC 01-R9 (14)	0.06	0.35					1.80	0.70
C1038/3524-04 (15)		0.56			0.62	1.97	2.76	
NCHRP 392 (16)	0.05	0.30				0.75	1.75	
NCHRP 306 (17)	0.06	0.32			0.87	1.44	2.33	0.90
Texas Pvt. Mrk. Handbook (18)	0.08	0.30				2.50	2.57	1.00
TxDOT Bid New (11)		0.27	0.32				2.02	
TxDOT Bid Maintenance (12)		0.15	0.31					
Other Sources		0.29	0.51	1.15	0.75	1.10	3.00	
RANGE ($)	0.06-0.10	0.15-0.56	0.28-0.78	0.60-1.15	0.50-0.88	0.75-2.60	1.75-3.00	0.68-1.00
Expected TxDOT Cost ($)	0.08	0.15 or 0.27	0.32	0.65	0.75	1.50	2.75	0.85

Table 24. Range of Pavement Marking Service Life (Years).

Source	Paint 4"	Thermo 4" (Flat) 100 mil	Thermo 6" (Flat) 100 mil	Thermo 4" (Inverted Profile)	MMA 4" (Splatter)	Tape 4"	Polyurea 4"
TTI 4150-2 *(13)*	.2-1	1-5			3-8	4-8	2-5
PTI 2006-06 *(10)*	0.25-3	1-7				2-8	3-4
VTRC 01-R9 *(14)*	1	3				6	3
C1038/3524-04 Freeway *(15)*		0.7-3		0.5-2.5	0.7-2	1-2.1	
C1038/3524-04 Non-Freeway *(15)*		2.4-3.8		2-2.1	2.5-3.5	1.9-4.6	
NCHRP 392 *(16)*	0.25-1	3-6			2-6	3-6	
NCHRP 306 *(17)*	0.25-1.5	1-3.4		0.9-3	0.6-2.9	1.2-3.4	
Texas Pvt. Mrk. Handbook *(18)*	1	3-4			5	4	4
Other Sources			2-4	4-6		4-6	
RANGE (years)	0.25-3	0.7-7	2-4	0.5-6	0.6-8	1.2-8	2-5

Table 25. Typical Pavement Marking Service Life (Years).

Source	Paint 4"	Thermo 4" (Flat) 100 mil	Thermo 6" (Flat) 100 mil	Thermo 4" (Inverted Profile)	MMA 4" (Splatter)	Tape 4"	Polyurea 4"
TTI 4150-2 *(13)*	1.0	2.0				4.0	4.0
PTI 2006-06 *(10)*	1.0	4.0				4.0	4.0
VTRC 01-R9 *(14)*	1.0	3.0				6.0	3.0
C1038/3524-04 Freeway *(15)*		1.9		1.5	1.2	1.6	
C1038/3524-04 Non-Freeway *(15)*		3.0		2.0	3.0	3.0	
NCHRP 392 *(16)*	0.6	4.5			4.0	4.0	
NCHRP 306 *(17)*	0.9	2.2		2.0	1.8	2.3	
Texas Pvt. Mrk. Handbook *(18)*	1.0	4.0			5.0	4.0	4.0
Other Sources			3.0	4.0		6.0	
RANGE (years)	0.6-1.0	1.9-4.5	3	1.5-4	1.2-5	1.6-6	3.0-4.0
Expected Service Life (years)	1	2 or 4	2 or 4	4	4	6	4.0

Cost and Service Life Summary

To get the true measure of the cost of the pavement markings, the service life of the marking needs to be accounted for so that more durable products that do not need to be restriped every year are on an even playing field with the cheaper, less durable markings that require more frequent applications. The cost and service life values in Table 23 and Table 25 are summarized in Table 26. Also in Table 26 are the estimated costs and service life values for the marking materials where no data were present. Typically, the service life was considered to be the same for materials that only differed by width. The rumble stripe cost is a combination of the milled shoulder texturing, surface preparation, and the thermoplastic pavement marking. The service life of the rumble stripe was assumed to be the same as for the standard thermoplastic. This is thought to be a conservative estimate because it has been shown that rumble stripes can reduce encroachment onto the pavement marking and thus increases the marking's service life (*8*).

Table 26. Costs and Service Life of Various Marking Materials.

Marking Material	Marking Width (inches)	Cost per Linear Foot ($/lf)	Service Life (years)	Cost per Year of Service	
				($/lf/yr)	($/mile/yr)
Paint	4	0.08	1	0.080	422.4
Thermo (Flat)	4	0.27	3	0.090	475.2
Thermo (Splatter)	4	0.65	3	0.217	1144
Thermo (Inverted Profile)	4	0.75	4	0.188	990
Thermo (Flat)	6	0.32	3	0.107	563.2
Thermo (Splatter)	6	0.85	3	0.283	1496
Rumble Stripe with Thermo	4	0.50	3	0.167	880
MMA (Splatter)	4	1.50	4	0.375	1980
MMA (Splatter)	6	2.10	4	0.525	2772
Tape	4	2.75	6	0.458	2420
Tape	6	3.75	6	0.625	3300
Polyurea	4	0.85	4	0.213	1122
RRPM Type II A-A	4	0.0375	3	0.0125	66
RRPM Type II C-R	4	0.0425	3	0.0142	74.8

Note: Pavement marking costs are estimates of expected bid prices for installed markings. Service life is estimated based on typical road and traffic conditions, or warranty periods. RRPM Price is $3.40 for a white/red marker, and spacing is assumed to be 80 feet.

Using the cost per linear foot and the service life in years, the cost per year of service for each of the marking materials can be determined. Table 26 also includes these values of cost per year of service. The lower cost per year of service for a pavement marking indicates a marking that would be more desirable from strictly a cost standpoint. Two costs per year of service values were determined, the cost per linear foot of marking per year and the cost per mile of marking per year. An example of this calculation would be a marking that cost $1500 to stripe a mile and has a service life of 3 years would have a $500 cost per mile of marking per year.

The determination of the costs of the RRPMs is based on the same principle as for the pavement markings. Since the RRPMs are generally spaced out, one RRPM can cover a large section of roadway. Typical spacing on highways is 40 or 80 feet. For these calculations 80 feet was used, but any spacing or number of RRPMs at a location can easily be factored in. An RRPM that cost $3.00 and is spaced at 80 feet would cost $0.0375 per foot of roadway marked, which equates to $198 to mark a mile. Factor in a three-year effective service life, and the cost to mark a mile over the service life of the marking is $66 per year.

DELAY AND SAFETY ASPECTS OF STRIPING AND RESTRIPING

In addition to the costs of the pavement markings themselves and the related pavement marking costs indicated in Table 21, there are secondary costs that are not directly related to the pavement markings. These secondary costs can include delay to motorists during striping activities and the cost of safety related expenses. Both of these secondary costs are highly variable depending on the road being striped and the planning of the striping operations. The less durable a marking is, the more often the road will need to be restriped, thus increasing delay costs and reducing the cost-effectiveness of the marking. The increased demand for roadway restriping from the use of less durable markings also increases the workload for striping crews, which increases the likelihood of striping crews falling behind. If striping crews fall far enough behind, safety could be compromised. With proper planning, marking selection, and management these costs can be reduced greatly, and safety can be improved.

Delay to motorists is a factor of several variables, including amount of traffic, roadway classification, type of work zone, speed of installation, and material being applied. The ability to use a marking that can be applied over the pre-existing marking, negating the need for removal or surface preparation, will negate the additional delay and safety concerns that these activities would impose. A major advantage to using more durable markings is the fact that they do not need to be restriped as often as less durable markings; thus, delay due to striping activities is reduced.

The amount of traffic on a roadway depends on the location of the road and the time of day. To minimize delay, striping activities should take place during the time of the day when moderate and high volume roads see lower traffic volumes, such that closing a lane will not impose delay. Striping during the time of the day when traffic volumes are the lowest could also be considered a safety benefit because with less traffic there will be less chance for an accident. Low volume roads will not see much delay regardless of the time of striping.

The roadway classification is also a factor, as facilities with multiple travel lanes in a single direction versus only a single lane pose very different scenarios. With multilane facilities the traffic will still be able to pass the striping operation whereas on roads with only one travel lane, passing the striping operation is much more difficult. With multilane facilities a temporary lane closure can be established if needed, providing safety to the stripers. If only one travel lane is present, a mobile work zone needs to be used. This mobile work zone would cause delay to drivers and when large queues form should allow vehicles to pass to reduce the delay.

The speed of installation is a function of the marking material being applied. Materials that can easily be applied in a mobile operation at the greatest speed will reduce delay imposed on motorists. Typically, spray pavement markings are the quickest to install. Another factor to consider is the rate at which the pavement marking material cures or dries, in the conditions that are present, to the point at which traffic can drive on it. This is referred to as a markings "no track" time. Markings that take a long time to dry may require a temporary lane closure, and thus may not be an option to be applied on roads other than multilane facilities.

A recent report by Cottrell and Hanson for the Virginia Transportation Research Council analyzed the cost of traffic delay imposed by striping activities (*14*). They found that delay imposed by striping activities on moderate and high volume roadways could be offset by striping during the off-peak hours. They still recommended durable markings on moderate and high volume roadways as they are better able to handle the higher traffic volumes. They also found that the delay on low volume roadways was not a major factor in determining the cost-effectiveness of a marking.

DRY AND WET VISIBILITY

The goal of all pavement markings, regardless of cost, is to provide adequate visibility of the marking. The visibility of a marking is a factor that should be considered when determining the best marking to use. There are several measures of pavement marking visibility, two of which are maximum detection distance and measured retroreflectivity. Several factors affect the dry and wet visibility of pavement markings. Both material binder and beads influence visibility as does the application type, such as agglomerate (splatter), inverted profile, flat, rumble, or wider markings. Each of these various marking application types comes at an additional cost as compared to the standard 4-inch wide flat marking.

All visibility data in this section is based on new markings and initial retroreflectivity measurements. Retroreflectivity value will decrease over time as the markings age. The decrease in retroreflectivity and visibility may not change uniformly across the various marking types. Typically, the higher retro products will lose a greater percentage of their retroreflectivity in the first year of service than do lower retroreflectivity products.

Detection Distance and Retroreflectivity

The maximum detection distance of 18 pavement markings in dry and rainy conditions at night was measured. The dry and continuous wetting retroreflectivity of these markings was also measured. The results of these data are displayed in Table 27. From the table it can be seen that higher retroreflectivity generally results in longer detection distances. The longer detection distance indicates what is regarded as a better pavement marking. The data from Table 27 is used to complete the rest of the visibility analysis (preview time and cost visibility comparison).

Preview Time

An interesting way to demonstrate a marking's visibility is to indicate the amount of preview time the marking provides based on its maximum detection distance. Adequate preview time is needed to indicate changing road geometries ahead to allow sufficient time to comfortably navigate the road. Using the detection distances from Table 27 for both dry and wet conditions allows for the calculation of preview time for a given speed.

Table 28 indicates the provided preview time for each of the pavement markings. Preview times are provided for a vehicle traveling at 30, 45, 55, and 65 miles per hour in either a dry or wet-night condition. The preview times in Table 28 are highlighted to show preview times that are in a similar range. All times greater than 4 seconds are in blue, times greater than 3 seconds but less than 4 seconds are in green, times greater than 2 seconds but less than 3 seconds are in yellow, and times below 2 seconds are in orange. Previous research studies have indicated that between 1.8 and 3.65 seconds of preview time is needed (*19,20,21*).

Looking at the results of the provided preview time, it can be seen that in the dry condition all of the markings provided more than 2.4 seconds of preview time at 65 mph. Seven of the pavement markings provided a preview time of greater than 3.2 seconds in the dry condition at 65 mph. All seven of these markings are not standard TxDOT markings.

Table 27. Pavement Marking Performance Data.

Marking Number	Marking Material	Visibility Distance (Dry, ft)	Visibility Distance (Wet, ft)	Dry R_L	Continuous Wetting R_L
8	Polyurea 4"	371	164	1967	100
11	Thermo 4" (Splatter)	308	156	777	52
12	Thermo 6" (Splatter)	307	173	695	47
13	MMA 6" (Splatter)	277	173	459	43
14	MMA 4" (Splatter)	260	175	392	165
17	Tape 4"	318	196	1011	398
19	Thermo 4" (Inverted Profile Diamond)	320	168	788	85
20	Thermo 6" (Splatter)	329	183	675	108
24	Tape 6"	333	211	1140	401
34	Thermo 4" (Flat) Type II Bead	265	139	532	20
35	Thermo 4" (Rumble Stripe) Type II Bead	237	161	521	40
37	Thermo 6" (Flat) Type II Bead	237	148	321	38
38	Thermo 4" (Flat) Type II Bead	229	150	360	39
39	Thermo 4" (Flat) Type III Bead	264	169	480	75
40	Thermo 6" (Flat) Type III Bead	251	152	420	77
41	Thermo 4" (Rumble Stripe) Type III Bead	250	160	469	96
42	Thermo 4" (Rumble Stripe) Type III Bead	239	160	457	97
43	Thermo 4" (Inverted Profile Transverse) 4"	281	182	611	325

Table 28. Preview Time Provided by the Various Pavement Marking Systems.

Marking Number	Marking Material	Preview Time at Indicated Speeds for Indicated Conditions (Seconds)							
		Dry-Night Conditions				Wet-Night Conditions			
		30mph (44fps)	45mph (66fps)	55mph (81fps)	65mph (95fps)	30mph (44fps)	45mph (66fps)	55mph (81fps)	65mph (95fps)
8	Polyurea 4"	8.43	5.62	4.60	3.89	3.73	2.48	2.03	1.72
11	Thermo 4" (Splatter)	7.00	4.67	3.82	3.23	3.55	2.36	1.93	1.64
12	Thermo 6" (Splatter)	6.98	4.65	3.81	3.22	3.93	2.62	2.14	1.81
13	MMA 6" (Splatter)	6.30	4.20	3.43	2.91	3.93	2.62	2.14	1.81
14	MMA 4" (Splatter)	5.91	3.94	3.22	2.73	3.98	2.65	2.17	1.84
17	Tape 4"	7.23	4.82	3.94	3.34	4.45	2.97	2.43	2.06
19	Thermo 4" (Inverted Profile Diamond)	7.27	4.85	3.97	3.36	3.82	2.55	2.08	1.76
20	Thermo 6" (Splatter)	7.48	4.98	4.08	3.45	4.16	2.77	2.27	1.92
24	Tape 6"	7.57	5.05	4.13	3.49	4.80	3.20	2.62	2.21
34	Thermo 4" (Flat) Type II Bead	6.02	4.02	3.29	2.78	3.16	2.11	1.72	1.46
35	Thermo 4" (Rumble Stripe) Type II Bead	5.39	3.59	2.94	2.49	3.66	2.44	2.00	1.69
37	Thermo 6" (Flat) Type II Bead	5.39	3.59	2.94	2.49	3.36	2.24	1.83	1.55
38	Thermo 4" (Flat) Type II Bead	5.20	3.47	2.84	2.40	3.41	2.27	1.86	1.57
39	Thermo 4" (Flat) Type III Bead	6.00	4.00	3.27	2.77	3.84	2.56	2.10	1.77
40	Thermo 6" (Flat) Type III Bead	5.70	3.80	3.11	2.63	3.45	2.30	1.88	1.59
41	Thermo 4" (Rumble Stripe) Type III Bead	5.68	3.79	3.10	2.62	3.64	2.42	1.98	1.68
42	Thermo 4" (Rumble Stripe) Type III Bead	5.43	3.62	2.96	2.51	3.64	2.42	1.98	1.68
43	Thermo 4" (Inverted Profile Transverse) 4"	6.39	4.26	3.48	2.95	4.14	2.76	2.26	1.91
	RRPM Type II C-R	22.73	15.15	12.35	10.53	12.5	8.33	6.79	5.79

Note: Preview time color scale; Blue ≥ 4 seconds, Green ≥ 3 seconds & < 4 seconds, Yellow ≥ 2 seconds & < 3 seconds, and Orange < 2 seconds.

In the wet condition the markings did not provide nearly as much preview time as in the dry condition due to the rain reducing the visibility of the markings. Only the tape products were able to provide more than 2 seconds of preview time at 65 mph. Even at 45 mph, only the tape product provides more than 3 seconds of preview time. If wet-night visibility is a major concern, then picking a marking with good wet-night performance is critical. Another means to provide wet-night performance is to supplement the marking with RRPMs, which is the current TxDOT standard practice.

COST AND VISIBILITY

Comparing the pavement marking cost per mile per year of service life to the visibility of the markings is a way to determine the marking that is the most cost-effective. Table 29 has the dry and wet detection distances as well as the cost of the various marking materials. The table is highlighted in green, yellow, and red to indicate which markings perform better or worse than the others. The markings that are highlighted in green have a dry preview time greater than 3.8 seconds, a wet preview time greater than 2.2 seconds, and/or cost less than 750 dollars per mile per year. The markings that are highlighted in orange have a dry preview time less than 3 seconds, a wet preview time less than 2 seconds, and/or cost more than 1250 dollars per mile per year. The markings that are highlighted in yellow have preview times and costs that fall between the values associated with the green and orange highlighted markings.

Looking at Table 29 it is apparent that the markings that provide the best visibility are the most expensive and the markings that are less visible are the least expensive. Markings 17, 20, and 24 all provide good detection distance in both the dry and wet conditions (the only markings to do this). These same three markings though are three of the most expensive markings. On the other hand, markings 37 and 38 provided poor visibility in both the dry and wet conditions (the only markings to do this). These same two markings though are two of the least expensive markings. These markings do not necessarily make the best compromise of visibility and cost.

Pavement markings 39, 8, 19, and 43 all have good or somewhat good visibility, and good or somewhat good costs. Marking 39 is standard thermoplastic with Type III beads. This marking provides less overall visibility compared to the others, but it is the least expensive marking. The other three markings are a little more expensive but provide increased visibility. It should be noted that the RRPMs used to supplement the pavement markings will provide greater visibility in both dry and wet conditions. The cost of RRPMs and standard markings is less expensive than just using a highly visible but expensive marking.

Another way to compare marking visibility and service life cost is to determine the amount of visibility per dollar spent. The value of visibility per dollar spent in both dry and wet conditions is indicated for each of the markings in Table 30. The visibility per dollar spent is determined by dividing the detection distance of the marking by the cost per linear foot per year of service of the marking. The higher the visibility per dollar spent value, the better.

Table 29. Visibility and Cost Comparison.

Marking Number	Marking Material	Detection Distance (Dry, ft)	Detection Distance (Wet, ft)	COST ($/mile/yr)
8	Polyurea 4"	371	164	1122
11	Thermo 4" (Splatter)	308	156	1144
12	Thermo 6" (Splatter)	307	173	1496
13	MMA 6" (Splatter)	277	173	2772
14	MMA 4" (Splatter)	260	175	1980
17	Tape 4"	318	196	2420
19	Thermo 4" (Inverted Profile Diamond)	320	168	990
20	Thermo 6" (Splatter)	329	183	1496
24	Tape 6"	333	211	3300
34	Thermo 4" (Flat) Type II Bead	265	139	475
35	Thermo 4" (Rumble Stripe) Type II Bead	237	161	880
37	Thermo 6" (Flat) Type II Bead	237	148	563
38	Thermo 4" (Flat) Type II Bead	229	150	475
39	Thermo 4" (Flat) Type III Bead	264	169	475
40	Thermo 6" (Flat) Type III Bead	251	152	563
41	Thermo 4" (Rumble Stripe) Type III Bead	250	160	880
42	Thermo 4" (Rumble Stripe) Type III Bead	239	160	880
43	Thermo 4" (Inverted Profile Transverse) 4"	281	182	990
	RRPM Type II C-R	> 1000	> 550	74.8

Like the results based on Table 29, the results based on the visibility per dollar spent indicated that the more expensive markings do not necessarily make the best compromise between cost and visibility. Again pavement marking 39 appears to be the best marking based on its dry and wet values. It can also be seen that the RRPMs provide a visibility per dollar spent value that is seven times greater in dry conditions and eight times greater in wet conditions than any of the other markings.

Table 30. Visibility per Dollar Spent.

Marking Number	Marking Material	Detection Distance (Dry, ft)	Detection Distance (Wet, ft)	COST ($/ft/yr)	Visibility per Dollar Spent (Dry, ft)	Visibility per Dollar Spent (Wet, ft)
8	Polyurea 4"	371	164	0.213	1742	770
11	Thermo 4" (Splatter)	308	156	0.217	1419	719
12	Thermo 6" (Splatter)	307	173	0.283	1085	611
13	MMA 6" (Splatter)	277	173	0.525	528	330
14	MMA 4" (Splatter)	260	175	0.375	693	467
17	Tape 4"	318	196	0.50	636	392
19	Thermo 4" (Inverted Profile Diamond)	320	168	0.188	1702	894
20	Thermo 6" (Splatter)	329	183	0.283	1163	647
24	Tape 6"	333	211	0.667	499	316
34	Thermo 4" (Flat) Type II Bead	265	139	0.09	2944	1544
35	Thermo 4" (Rumble Stripe) Type II Bead	237	161	0.167	1419	964
37	Thermo 6" (Flat) Type II Bead	237	148	0.107	2215	1383
38	Thermo 4" (Flat) Type II Bead	229	150	0.09	2544	1667
39	Thermo 4" (Flat) Type III Bead	264	169	0.09	2933	1878
40	Thermo 6" (Flat) Type III Bead	251	152	0.107	2346	1421
41	Thermo 4" (Rumble Stripe) Type III Bead	250	160	0.167	1497	958
42	Thermo 4" (Rumble Stripe) Type III Bead	239	160	0.167	1431	958
43	Thermo 4" (Inverted Profile Transverse) 4"	281	182	0.188	1495	968
	RRPM Type II C-R	> 1000	> 550	0.0425	23529	12941

BENEFIT-COST SUMMARY

To be the most cost-effective pavement marking, the marking must have a low cost per year of service life, have adequate visibility, and not be difficult to install and maintain. Spray thermoplastic is similar to paint in yearly cost. When delay imposed by striping activities is factored in, spray thermoplastic markings can be more cost-effective because of their longer durability. The use of the most durable markings on the highest average daily traffic (ADT) roadways is beneficial so the markings last for multiple years, and these benefits are maximized on major highway connector ramps where striping activities could cause major delay and safety concerns. Inverted profile thermoplastic and rumble stripes may be viable alternatives as they may be able to provide enhanced visibility, especially in wet-night conditions. Polyurea may also be a viable alternative for PCC pavements as it is generally more compatible with PCC than thermoplastic, resulting in greater durability that may offset the higher initial costs. MMA and tape products are currently much more expensive than other marking types. Tape products are expensive but have several advantages: (1) if properly installed they are the best performer on PCC surfaces, (2) they can provide greater visibility than other markings in both wet and dry conditions, (3) they come with a warranty from the manufacturer, and 4) they can easily be configured into a contrast marking product. Overall, currently the most cost-effective system for Texas is spray-applied thermoplastic with supplemental RRPMs, although special situations may necessitate alternative treatments (e.g., PCC pavement and very high ADT roadways).

CHAPTER 4: CONTRAST PAVEMENT MARKINGS

Contrast markings are a means to improve the visibility of pavement markings by providing better contrast with the pavement surface. During the daytime, visibility of pavement markings is governed by the contrast of the marking with the pavement surface. White pavement markings tend to have lower contrast and thus are less visible on Portland cement concrete and light-colored (faded) asphalt pavement surfaces. Visibility of white markings as well as yellow markings on these light-colored surfaces may be improved with the use of black contrast markings *(13,18,22)*. This section of the report documents the literature review, study design, and study findings with respect to contrast markings. The researchers document the state-of-the-practice with respect to contrast markings for Texas and the United States, and they document public opinion with respect to the use of contrast markings on state roadways.

BACKGROUND

Recognition in the MUTCD

The current Manual on Uniform Traffic Control Devices (MUTCD) briefly mentions contrast markings, but does not provide any set criteria for their usage. The MUTCD indicates the possible colors for pavement markings, and that using these colors with a black marking can be considered a contrast marking. The MUTCD states, "Markings shall be yellow, white, red, or blue. The colors for markings shall conform to the standard highway colors. Black in conjunction with one of the above colors shall be a usable color. Black may be used in combination with the above colors where a light-colored pavement does not provide sufficient contrast with the markings. When used in combination with other colors, black is not considered a marking color, but only a contrast-enhancing system for the markings" (*23*). The Texas MUTCD states the same information in regard to contrast markings (*24*). These sources do not specifically indicate whether the black portion of a contrast marking has to be retroreflective or not. It is implied though that since it is not considered a marking color, as stated in the above quotation, and since it does not need to be visible at night, that the black portion of a contrast marking does not need to be retroreflective.

Contrast Marking Design Types

There are three typical designs for contrast markings: boxed, bordered, and lead-lag. The boxed and bordered designs are very similar, except that the boxed design has black all around the marking whereas the bordered only has black on the sides. The lead-lag design is a black marking placed either before or after a standard white pavement marking.

The boxed design contrast marking is created by first applying a black marking to the roadway. This black marking must exceed the dimensions of the white marking that is to be applied. After the black marking is applied, the white marking is applied over the top of it, leaving a border around the white marking. Boxed contrast markings are only applicable to skiplines, as a box cannot be placed around edge lines. Figure 18 gives an example of a boxed contrast marking.

The TxDOT Houston district has tried using black 6-inch thermoplastic markings with a white 4-inch thermoplastic marking placed on top. Initially, the thought appeared to be worth exploring, especially since the black thermoplastic could be formulated to bond to the PCC so that the white thermoplastic on top would stay down (a typical problem with thermoplastic is that it does not bond to PCC very well). Unfortunately, the experience was not favorable; the white material began to melt and intermix with the black and the edge between the black and white was not as uniform as desired. This complication seems correctable for future applications, given proper testing and material formulation.

The bordered contrast marking is currently only a preformed tape design. The tape product has the marking color in the center with black stripes on either side. The marking color and the black border can both vary in width. The typical pattern of the tape is a 4-inch or 6-inch wide white stripe with a 1.5-inch wide black border on each side. Because the black is only on the sides of the marking, the markings can be placed as either skip or edge lines. Figure 19 gives an example of both skip and edge lines with a border contrast marking.

The lead-lag design has a typical pavement marking either followed by a black marking or preceded by a black marking. Like the boxed design, this design is only applicable to skiplines. The black marking can be the same width or wider than the actual pavement marking. In some cases, the black portion may connect the white skiplines, creating a solid marking of white skiplines connected with black lines. Figure 20 gives an example of a lag contrast marking, also known as a shadow contrast marking.

Figure 18. Boxed Contrast Marking (Atlanta, Texas).

Figure 19. Bordered Contrast Markings, Skip and Edge (Waco, Texas).

Figure 20. Lag or Shadow Contrast Marking (Houston, Texas).

When Are Contrast Markings Implemented?

Contrast markings can be used at any location where the visibility of the pavement markings is poor, usually due to a light-colored pavement surface such as PCC and faded asphalt surfaces. Because of the increased expenses of applying a contrast marking, they are often used only for white skiplines on divided highways with light-colored pavements (*13,24*). There is no standard for when a contrast marking should or should not be placed. There are also no standards for the type of contrast marking to be placed. With numerous designs and many variations of each design, it is impossible to know which design is the most cost-efficient or most beneficial without adequate research.

What is Contrast?

It appears that retroreflectivity has been the focus of much of the pavement marking research. However, retroreflectivity is only useful during nighttime. During the daytime, the pavement markings need to be visible as well, and this visibility is governed by the daytime contrast of the pavement marking. Daytime contrast and nighttime contrast of a pavement marking are two different values, measured under different conditions. The contrast of a pavement marking tells how well the pavement marking stands out from the pavement surface.

Nighttime contrast is a measure of the relationship between the coefficient of retroreflected luminance of the pavement marking with the coefficient of retroreflected luminance of the pavement surface. The symbol for the coefficient of retroreflected luminance is R_L. The coefficient of retroreflected luminance is commonly referred to as retroreflectivity. Nighttime contrast of a marking is assumed to occur under headlamp illumination.

$$Nighttime\ Contrast = \frac{\left(R_{L(Marking)} - R_{L(Pavement\ Surface)}\right)}{R_{L(Pavement\ Surface)}}$$

Daytime contrast is a measure of the relationship between the luminance coefficient in diffuse illumination of the pavement marking with the luminance coefficient in diffuse illumination of the pavement surface. The symbol for the luminance coefficient in diffuse illumination is Q_d. Daytime contrast of a marking is assumed to occur during the day under cloudy conditions or during the night under roadway lighting.

$$Daytime\ Contrast = \frac{\left(Q_{d(Marking)} - Q_{d(Pavement\ Surface)}\right)}{Q_{d(Pavement\ Surface)}}$$

Diffuse reflection is the major component in daytime contrast. Diffuse reflection is reflection inherent in the color of the surface. This is why light-colored pavements have low contrast levels because the pavement marking color is similar to that of the pavement surface. The difference between diffuse reflection and retroreflection is that light is scattered in all directions under diffuse reflection, but under retroreflection, much of the light is returned toward the light source. Figure 21 is an example of these two types of reflection of light.

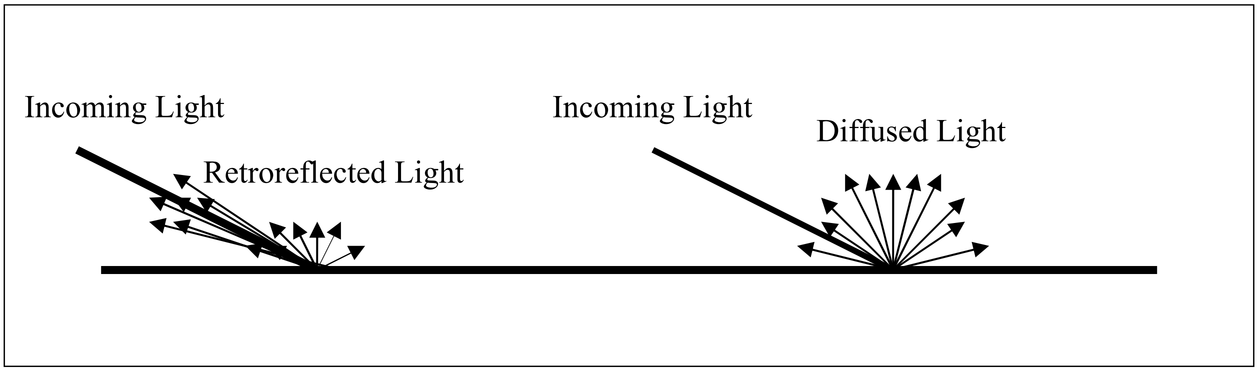


Figure 21. Examples of Reflection of Light.

A third kind of reflection that plays a role in contrast is specular reflection. Specular reflection can be thought of as opposite to retroreflection. Most of the light in specular reflection is reflected away from the light source. Whereas diffuse reflection usually occurs on a rough surface, specular reflection typically occurs on a smooth surface. Specular reflection plays a major role in contrast when the pavement surface is wet because the water acts to smooth out the pavement surface. As specular reflection increases due to the buildup of water on the pavement surface, diffuse reflection decreases. Specular reflection also plays a major role when the sun is shining on the pavement surface.

All three types of reflection always occur; it's just that they always occur at different rates for different situations. During the day there is very little retroreflection, but high levels of diffuse and specular reflection. During nighttime conditions, retroreflection plays a larger role than during the day. During wet conditions, specular reflection is the dominant type of reflection. Of concern for daytime contrast markings, though, is diffuse and specular reflection.

Contrast Marking Usage in the United States

Statewide Usage Survey

In 2002, the Pennsylvania Department of Transportation (PennDOT) surveyed the American Association of State Highway and Transportation Officials (AASHTO) Traffic Engineering committee to determine the use of contrast markings around the U.S. They received

35 responses, and 8 of those indicated that contrast markings were being used. The results of the survey indicated that there were no research studies on the use of the contrast markings.

Table 31 shows the states that provided comments and includes a list of the states that responded that they do not use contrast markings and provided no comments.

A more recent study by the Utah DOT (UDOT) has shown that the number of states using contrast markings has not changed much. The specific questions that were asked in the Utah survey were:

1. Does your state use contrast markings (black paint) on concrete road surfaces?
2. Has any research been done in your state to identify a cost to benefit ratio for contrast markings?
3. If your state uses contrast markings, what pattern is used?

There were only 19 responses to the Utah survey. Even though the Utah survey was two years after the PennDOT survey, the percentage of contrast marking users was about the same, 22 percent. Furthermore, there were no new comments related to the patterns being used or tested. Most important, however, was the fact that research had still not been conducted on contrast markings.

Table 31. PennDOT Statewide Contrast Marking Survey Results in 2002.

State	Currently Use Contrast Markings?	Any Safety Studies?	Current Practice
Arizona	No	-	In the process of including black contrast markings for the I-10 tunnel. They will be using 3M Tape, Series 380I-5.
Florida	Yes	-	Uses 6-inch black lines connecting white skiplines.
Georgia	Yes	No	Uses 3M's 380 Tape with a 5-inch white line with 1.5 inches of black on both sides. Used on new PCC expressways, freeways, and bridges as they are let.
Iowa	No	-	Used experimentally once.
Illinois	Limited	No	Used 1-inch black on the sides.
Maryland	Yes	-	Uses white markings with black edges.
Michigan	No	-	Has installed about 10 miles of contrast markings, but have very little PCC pavements and very little epoxy.
Nevada	Trial Basis	No	Does not have a policy, but experimented on a couple of projects. Commented that they are great on PCC.
New Hampshire	No	-	There are some black contrast markings on local roads, but the DOT has virtually no PCC roadways.
New Jersey	Yes	No	Have used both epoxy contrast tape and 3M tape on several interstate highways, and prefers the 3M tape.
North Carolina	Yes	No	Install contrast markings on all PCC roads and bridges on the NHS. A black skip marking is applied immediately following, and of the same dimensions as the white skip markings.
Pennsylvania	Yes	No	Currently targeting all skiplines on expressways and freeways with PCC surface, using 6-inch by 10 foot black markings immediately after the white skip markings. PennDOT has achieved about 30 percent of their objective.
South Carolina	Yes	No	On all PCC interstate highways, using 6-inch by 5 foot trailing black; or 3M tape with 5-inch white and 1.5 inches of black on both sides.
Virginia	Yes	No	No statewide policy. Typically, installed on PCC roadways on the limited access system, but this is at the decision of each of the nine construction districts in the state. There are situations where one district has also installed them on asphalt that is bleached to the point that it is white enough for black contrast markings to be effective. Other situations where they may be used include bridges and overpasses along interstate roadways and major arterial roadways (4-lane divided). In most cases, tape is used with 1.5 inches of black on both sides of the marking. One district used 4-inch by 10-foot black markings after the white skiplines.
Wyoming	No	No	Had experimented on three-lane highways (truck-climbing lanes) using 3M tape with black boarder.
Puerto Rico	Yes	No	Recently installed 6-inch white over 12-inch black on major toll roads. Had good public response noting improved visibility.
States that responded to the survey that do not use contrast markings and did not provide comments.			Alaska, Connecticut, Idaho, Indiana, Iowa, Kansas, Kentucky, Maine, Massachusetts, Montana, Nebraska, New Mexico, New York, North Dakota, Oregon, Rhode Island, Tennessee, Washington, West Virginia

Past Research

As evident from the statewide surveys, states have not conducted much if any research on contrast pavement markings. As far as the researchers can tell, there have not been any studies focused on the best pattern to use for contrast markings, benefit-cost analysis of contrast markings, or setting criteria for the usage of contrast markings.

As previously mentioned, most research has focused on retroreflectivity and nighttime contrast. Little research has been conducted in regard to daytime contrast and what contrast values are necessary. Nighttime contrast research can be evaluated to find areas that would pertain to daytime contrast, such as the effects of pavement marking wear or the difference between pavement surfaces.

Migletz et al. conducted a field study of pavement markings in the fall of 1994 and then again in the spring of 1995 at study sites in Iowa and Michigan *(25)*. The study was conducted to determine the effects of the winter months and snow removal activities on the retroreflectivity and contrast of pavement markings on both PCC and asphalt road surfaces. The study showed that nighttime contrast ratios significantly decreased between the before and after period. The study also showed that in general PCC surfaces had lower nighttime contrast than asphalt surfaces. Another finding showed that white edge lines and skiplines have similar contrast ratios. In regard to daytime contrast, all of these findings seem pertinent and should be considered similar for daytime contrast conditions.

Another factor that is similar between nighttime driving and daytime driving is the effect of glare. During the nighttime, opposing vehicles' headlights cause glare, and during the daytime the sun causes glare. Disability glare is a glare source present in the visual field that impairs vision. Adrian found that the effects of the disability glare require that a pavement marking's contrast be higher than if there was no glare present to achieve the same level of visibility *(26)*. The COST 331 report found that profiled pavement markings might become virtually invisible when driving against the sun due to the specular reflection of the road and the marking *(19)*. The low degree of specular reflection off the profiled pavement marking compared to the high degree of specular reflection off the pavement surface is what causes the marking to seemingly disappear.

Pavement markings that are not clearly visible may lead to difficulty in lane keeping, and encroachment into adjacent lanes and shoulders. Allen et al. found that the probability of lane departure increased exponentially as contrast decreased (27). This finding holds true for both day and nighttime conditions, and suggests that a minimum contrast level should be determined to provide adequate contrast of markings.

COST 331 concluded that during high levels of daylight, the visibility of pavement markings is poor only when the daylight contrast is very low (*19*). Therefore, it is important to not allow the pavement surface and markings to reach a very low level of contrast with each other. The COST 331 report also indicated that with the high background luminance caused by daylight, visibility conditions tend to follow Weber's law (*19*). Weber's law says that the visibility distance of a marking may change from short to long with only a small improvement in contrast. This finding indicates that for pavement markings that are not very visible during the daytime due to poor contrast, a slight improvement to contrast can provide much better visibility of the markings.

Past Research Summary

It is evident that there is a lack of research into all aspects of contrast pavement markings. There are no studies on contrast marking design, contrast marking application procedures, criteria for implementing contrast markings, or the cost-effectiveness of contrast markings. One thing that is known, though, is that better contrast will result in more visible markings and thus better lane keeping.

ONLINE CONTRAST PAVEMENT MARKING SURVEY

As part of this research project, an online survey of the 25 TxDOT districts was conducted. This online survey was also sent to each state department of transportation to see any changes since the PennDOT and UDOT surveys. The goal of the survey is to assess the usage and performance of contrast pavement markings across the state of Texas and across the United States. The survey gathered information such as the reasons for using contrast markings, marking materials used, reasons for using the specific materials, marking design types, cost of contrast markings, ease/difficulty of installation, ease/difficulty of maintenance, and the outlook for future contrast marking. The full survey is included in Appendix C.

Survey Results

Surveys were sent to all 25 TxDOT districts as well as to all 50 states. After one month, those who had yet to respond were called and asked to complete the survey. In total, 33 of the 50 states responded to the survey, which was a similar percent response as the 2002 PennDOT survey. All 25 of the TxDOT districts responded to the survey. The following subsections will explore the responses to the surveys.

Current Contrast Marking Usage

Each of the respondents indicated that their area either uses or does not use contrast pavement markings. Of the 25 TxDOT districts, 16 said they use contrast pavement markings. Of the 33 states that responded, 21 indicated that they use contrast pavement markings. This is a large increase from the eight states that indicated that they used contrast markings in 2002. Table 32 indicates the usage rate for TxDOT and all states. Figure 22 indicates the TxDOT districts that use contrast markings. The districts that use contrast markings are in dark gray whereas the districts that do not use contrast markings are in light gray. Figure 23 indicates the states that responded to the contrast marking survey. The states that responded and use contrast markings are in dark gray, the states that responded and do not use contrast markings are in light gray, and the states that did not respond and thus whose current usage of contrast markings is unknown are in white. Figure 24 indicates a partial combination of the results from the PennDOT survey and this survey. The PennDOT survey provided data from four more states that use contrast markings, but never responded to the survey conducted for this study. Also included is one other state that did not respond to this survey that does not use contrast markings. The PennDOT survey also indicated four other states that at the time were not using contrast markings, but their status at this time is still unknown and was not included in Figure 24.

Table 32. Contrast Marking Usage.

Survey Summary Category	TxDOT		All States	
Response Rate	25/25	100%	33/50	66%
Use Contrast Markings	16	64%	21	64%
Do Not Use Contrast Markings	9	36%	12	36%

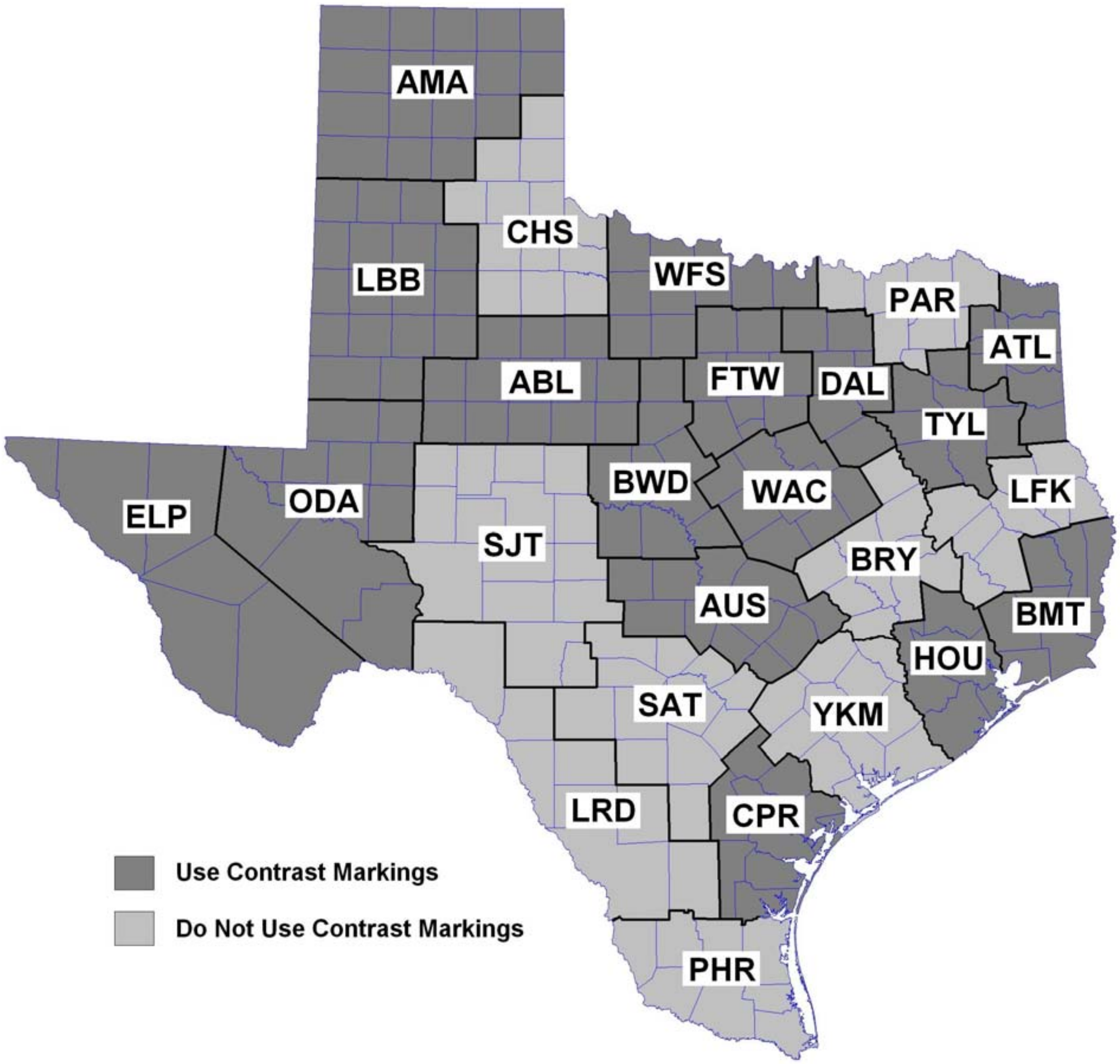


Figure 22. TxDOT Districts Using Contrast Markings.

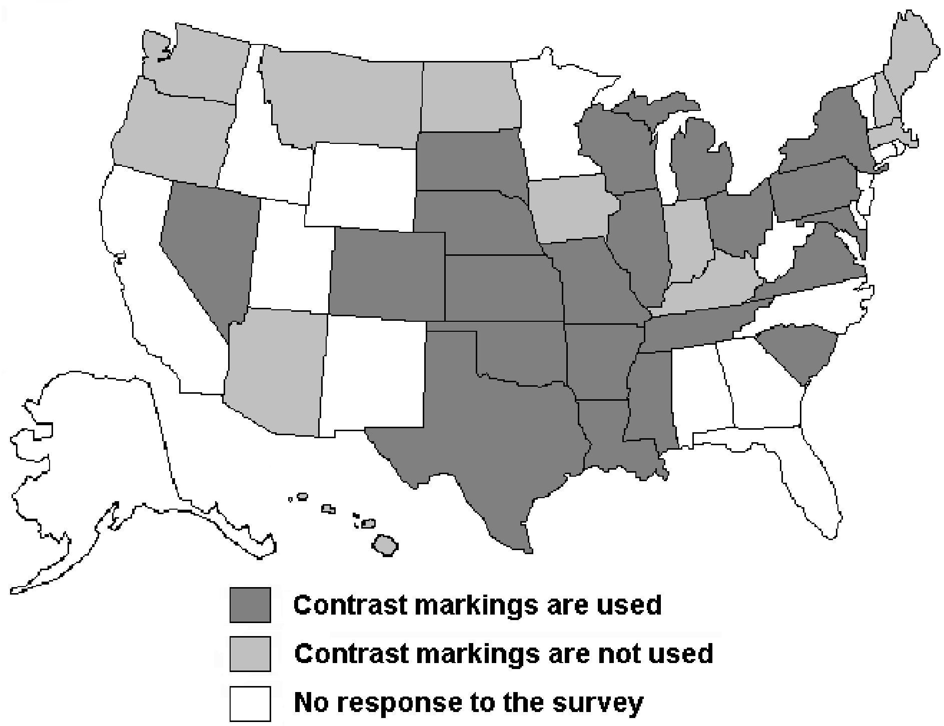


Figure 23. States Using Contrast Markings 2006 Survey.

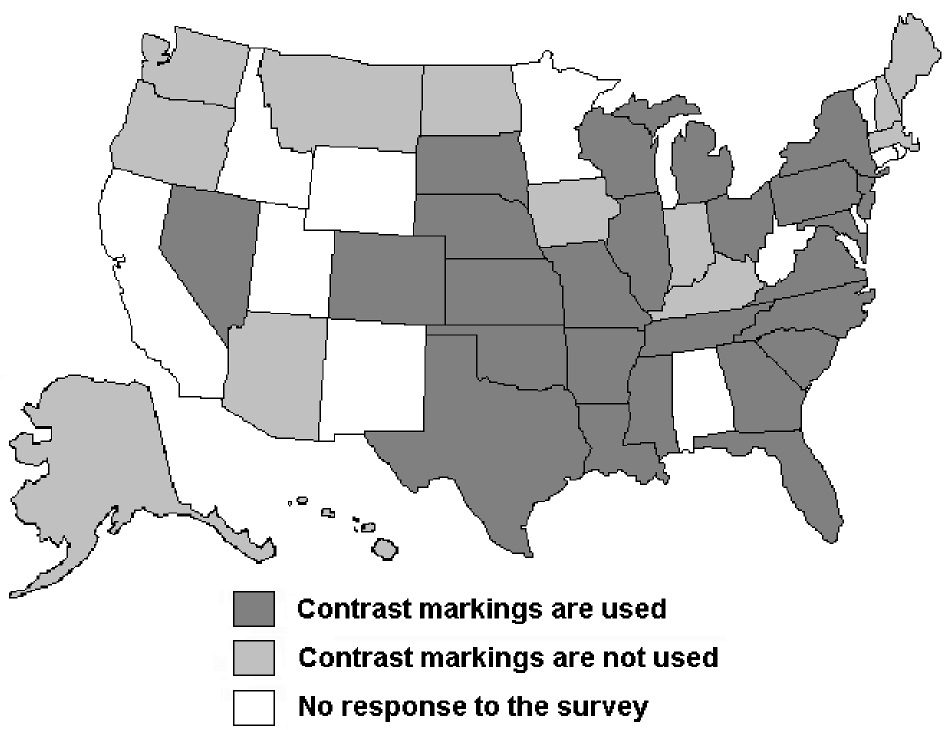


Figure 24. States Using Contrast Markings Combined 2006 and 2002 Surveys.

Each of the districts and states were asked why they use contrast markings. Table 33 gives the responses to the choices that were provided. The majority of the answers were to improve safety. The respondent input to the "other" selection was almost always to improve visibility of the pavement markings on PCC surfaces. This response could also be considered a safety improvement. The other most common response was that the contrast markings were being used on an experimental basis, indicating the limited experience of this form of pavement marking. Half the TxDOT districts and half of the responding states indicated that there was no set criteria for using contrast markings. Those who did say they had criteria for implementing contrast markings indicated that they are to be used on PCC roadways. Some surveys indicated that the general public has questioned the purpose of the contrast markings, indicating confusion as to the purpose of the black marking.

Table 33. Reasoning for Using Contrast Markings.

Reason for Using Contrast Markings	TxDOT		All States	
Improve Safety	11	46%	14	44%
Public Request	0	0%	1	3%
Trial/Experimental	5	21%	9	28%
Other areas have used them	0	0%	0	0%
Other	8	33%	8	25%

Contrast Marking Material Used

Many different types of pavement marking materials have been used for contrast marking application purposes. Table 34 indicates the frequency of the different pavement marking material types used for contrast markings. Contrast pavement marking tape is the most common type of contrast marking material used by both TxDOT and other states.

Table 34. Contrast Marking Material Used.

Marking Material	TxDOT		All States	
Paint	2	8%	4	13%
Tape	13	50%	16	53%
Plural Component (Epoxy, Polyurea, etc.)	5	19%	6	20%
Thermoplastic	6	23%	4	13%
Other	0	0%	0	0%

Table 35 indicates the reasoning behind the selection of the pavement marking materials selected in Table 34. Many of the responses were that the pavement marking materials were selected based on past performance or on an experimental basis. Past performance issues are ease of installation, maintenance, durability, and visual performance. Comments listed in the "other" category were pavement marking contracts, most of which involved warranty tape products.

Table 35. Reasoning for Using the Marking Material Type.

Reason for Marking Material Use	TxDOT		All States	
Cost	4	17%	5	13%
Experimental	7	29%	8	21%
Past Performance	8	33%	14	37%
Installation Parameters (temp, availability, etc.)	2	8%	6	16%
Other	3	13%	5	13%

Of interest was the method to apply and maintain the contrast pavement markings. Table 36 indicates the general application method of the markings. The application method depends on the type of material being applied and the marking design that is being implemented. Some marking systems can be applied with a single truck or with multiple trucks. Typically only the tape products are hand applied, but they can also be applied with a mobile tape applicator using standard tape application procedures.

Table 36. How Contrast Markings are Applied.

Application Type	TxDOT		All States	
Single Truck Application	13	81%	8	42%
Multiple Truck Application	1	6%	3	16%
Hand Applied	2	13%	5	26%
Don't Know	0	0%	3	16%

Typically, the pre-existing stripe is removed and the area cleaned before the contrast markings are applied. Most places indicated that they have not yet reapplied contrast pavement markings. Those who have replaced them indicated that the previous contrast marking was removed and the new one was installed; this was always the case for tape products.

Several of the TxDOT surveys noted that the black portion of the contrast marking has begun to fail prior to the white marking. Several state surveys indicated the exact opposite thing in that the white fails prior to the black. This is an interesting finding, with no obvious explanation from the data obtained. It should be noted that none of the surveys indicated wide scale premature failure of either the white or black portion of the contrast markings.

Design Types

There are many different designs of contrast pavement markings. Several were listed above near the beginning of this chapter. The survey included seven different designs that are known to have been used in the past. Figure 25 indicates the different designs in a two-skip layout with the direction of travel noted in the figure. Each of the designs is associated with the letter below it to indicate which selection matched each design.

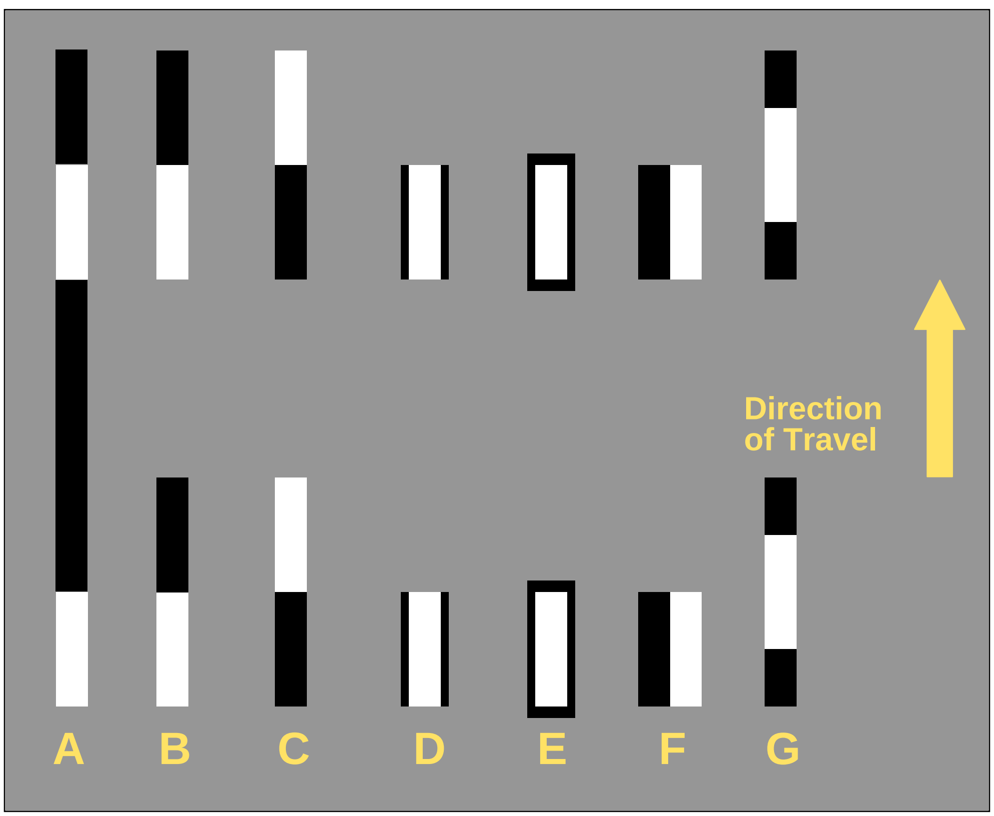


Figure 25. Diagram of Various Contrast Marking Designs.

Table 37 indicates the designs that are in use by TxDOT and the other states. The "other" selection was indicated to be a bordered marking with a short lead and long lag, much like the boxed marking. By far the most common type was the bordered marking that is a tape product, which was the most commonly used contrast marking material. The bordered marking as well as the lead and lag markings are the easiest of the contrast marking designs to implement and maintain.

Table 37. Contrast Marking Designs Used.

Marking Design	TxDOT		All States	
A: Continuous Black	0	0%	1	3%
B: Lag/Shadow	5	23%	6	17%
C: Lead	2	9%	3	8%
D: Bordered	9	41%	17	47%
E: Boxed	4	18%	7	19%
F: Side by Side	0	0%	0	0%
G: Half Lead, Half Lag	1	5%	2	6%
Other	1	5%	0	0%

Contrast Marking Costs

With the limited use of contrast pavement markings, cost data are even more limited. Many contrast marking projects are on a trial or experimental basis and, therefore, there is a limited amount of contrast markings being installed. This limited amount of marking applied and the status of being experimental sections can skew the costs of the markings. Pavement markings, like most things, decrease in unit cost as installation volume increases. Table 38 indicates the reported costs per linear foot for the various types of contrast markings. It was also noted that multi-polymers are about 25 percent of the cost of warranty tape. In addition, the higher cost materials are more durable and the benefits outweighed the additional costs, but no evidence was provided to support this statement. Comparison to typical marking costs is difficult because of the limited use of the markings creating a higher cost. It can be expected to pay at least one dollar more per linear foot for contrast tape products versus standard tapes. It can also be expected to pay two to three times the cost for other marking types. This increase in cost should be expected, though, even with the reduced amount of marking being applied. All of the contrast marking designs provide more pavement markings on the roadway by providing a wider or longer marking system.

Table 38. Contrast Marking Pricing.

Nation Wide		
Marking Material	**Cost**	**State**
Epoxy	$0.40	Pennsylvania
Tape	$4.75	South Dakota
	$5.24	Arkansas
	$1.00 more than standard tape	Wisconsin
Plural component	$.80-1.10	Oklahoma
State of Texas		
Marking Material	**Cost**	**District**
Epoxy and Polyurea	2x cost of standard marking	Lubbock
Tape	$5.00	Pharr
	$5.45	Corpus Christi
	$5.15-5.72	Tyler
	$4.00	Atlanta
Plural component	$1.00	Abilene
Thermoplastic	$1.00	Atlanta
Inverted profile thermoplastic	$2.00	Atlanta
Paint	$0.50	Atlanta

Future Contrast Marking Usage

Not only are current pavement marking practices of interest, but so are the anticipated future pavement marking practices. Table 39 indicates the anticipated future use of contrast pavement markings. Comparing the current usage to the anticipated usage, it can be seen that TxDOT plans on increasing contrast marking usage, but other states plan on reducing usage. There were several reasons noted for increased usage in Texas and decreased usage in other states. Texas has much more PCC than many other states, especially states in the north. Many TxDOT districts are beginning to apply contrast markings to all PCC surfaces, and are looking at expanding this practice to long bridge spans and connector ramps with PCC surfaces. Many northern states that have few miles of PCC do not see the benefit on asphalt roadways and do not plan on using them past an experimental stage. Also many states feel that dry and wet retroreflectivity as well as wider pavement markings are more important and beneficial than the contrast markings, and are directing funds in that direction. TxDOT also sees these needs, and is putting money into them as well.

Table 39. Future Use of Contrast Markings.

Response	TxDOT		All States	
Yes	19	79%	16	48%
No	5	21%	17	52%

LAPTOP CONTRAST PAVEMENT MARKING SURVEY

Study Design

The use of a laptop survey in the study approach was selected to meet the project objectives while maintaining a well-designed experimental plan. One of the primary benefits of a laptop survey is to obtain a large sample size of test subjects that fit a variety of demographics, such as age, education, driving experience, and region of residence. The larger and more diverse the sample size, the more representative the statistical findings will be of the study population; hence, the laptop survey approach can strengthen the analysis. To further validate this approach, previous research efforts that investigated the drivers' understanding of pavement markings were reviewed for their approach and specific results (*22*,*28*,*29*).

The study researchers reviewed pertinent literature and considered viable study designs. Previous studies had used diagrams to survey drivers, some used pictures, and some asked a series of situational questions using diagrams and pictures. More "real-world" scenarios considered include: (1) using in-vehicle testing techniques on closed-course facilities or even on the open road; or (2) simulator testing. However, given the objectives of this study, all of these techniques have limitations within the confines of this study.

After reviewing the investigation techniques that had been used in the past, in addition to in-vehicle testing and simulator testing, it was clear that a new approach would be needed for this study. While photographs can provide a rich environment of information, it was decided to use video in the survey. It was believed that video provided the test subjects with a more realistic driving environment because the visual information would be presented in a dynamic format rather than the static format of photographs.

Three limitations of any study that presents multiple treatments to test subjects are: cost, time, and confounding factors. Confounding factors for this study would be if the environment in which the video were recorded changed in any manner other than the treatments, such as lighting, vegetation, roadway alignment, signing, traffic patterns, etc. As for cost and time, every project has a budgetary limit and time constraint that restrict the number of treatments that can be tested. The researchers were able to devise a unique study design that was able to surmount these limitations.

The researchers were able to videotape one unmarked roadway, and then, using state-of-the-art video editing, they added 10 different types of pavement markings. This roadway was a highway segment along a newly constructed section of US183 in the Austin District. The roadway surface was new Portland cement concrete, a pavement surface that provides poor contrast with standard white pavement markings (see Figure 26). Subsequently, every test subject would view individual videos where the only change was the skipline pavement marking. Figure 27 contains all 10 pavement marking treatments tested. A standard 4-inch wide white marking was included to establish the baseline for how the other markings compare to what is already currently on roadways. The 6-inch and 8-inch wide marking treatments were included to see if test subjects believed a wider white marking would be more beneficial than the standard 4-inch wide marking, and to see if there is a preference between having wider markings or contrast markings.

Unmarked Road	Digitally Marked Roadway

Figure 26. Video Edited Roadway.

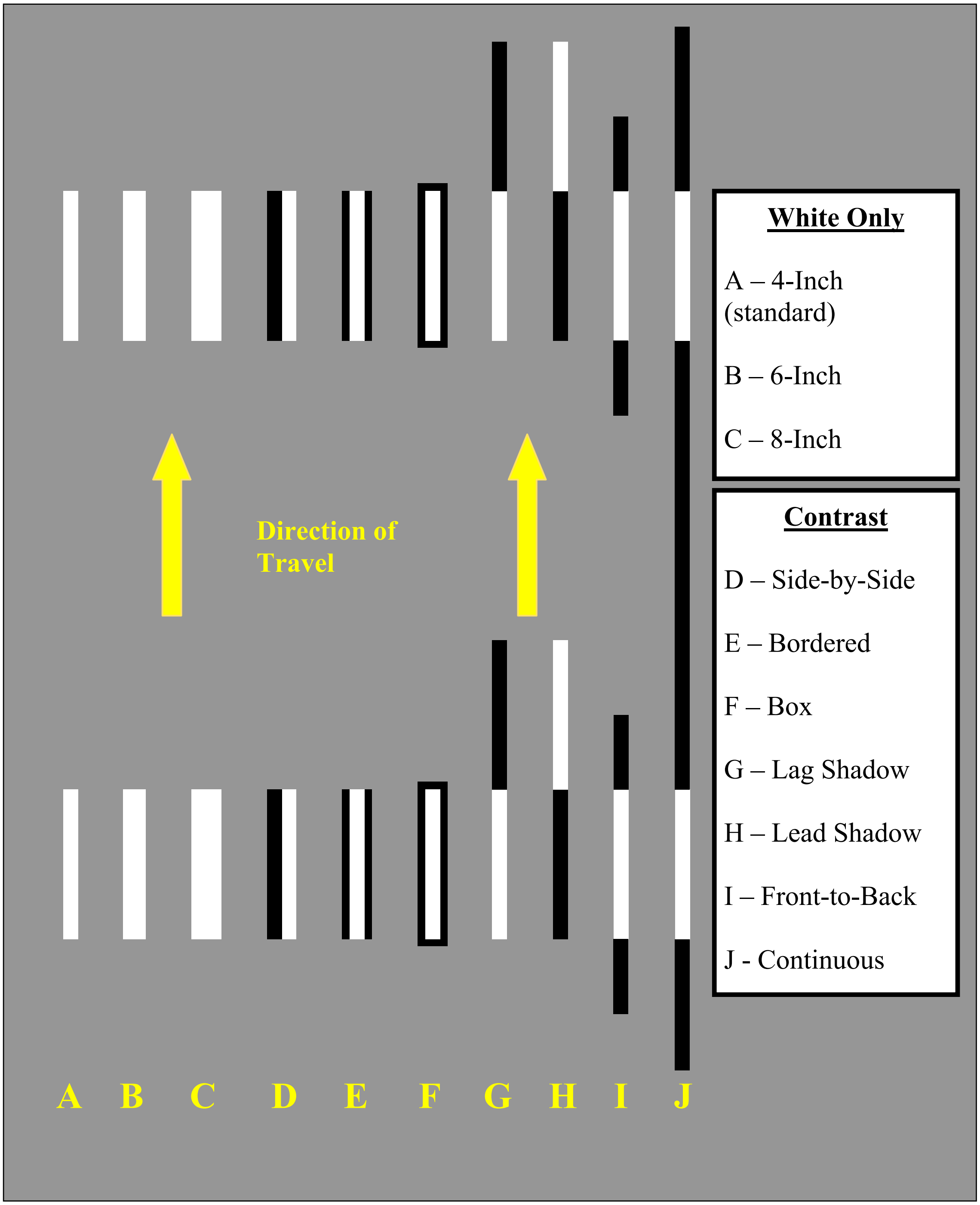


Figure 27. Marking Treatments.

The laptop survey was subdivided into four tasks. The first task consisted of a set of questions that gathered demographic information and each test subject's current knowledge and preference toward contrast markings. The second task was a rating task whereby the test subject preference toward contrast markings. The second task was a rating task whereby the test subject reviewed video footage of each of the 10 treatments. Underneath the video was a rating scale of 1 through 5 with 1 connoting the idea that the marking is very helpful in delineating the travel path, and 5 connoting that the marking is not helpful (see Figure 28). The standard 4-inch wide white skipline was always shown first, but the other treatments were randomly ordered to make two different surveys in order to minimize the possibility of bias. The mean values of these ratings would be compared to establish an initial ranking of test subject preference for each treatment.

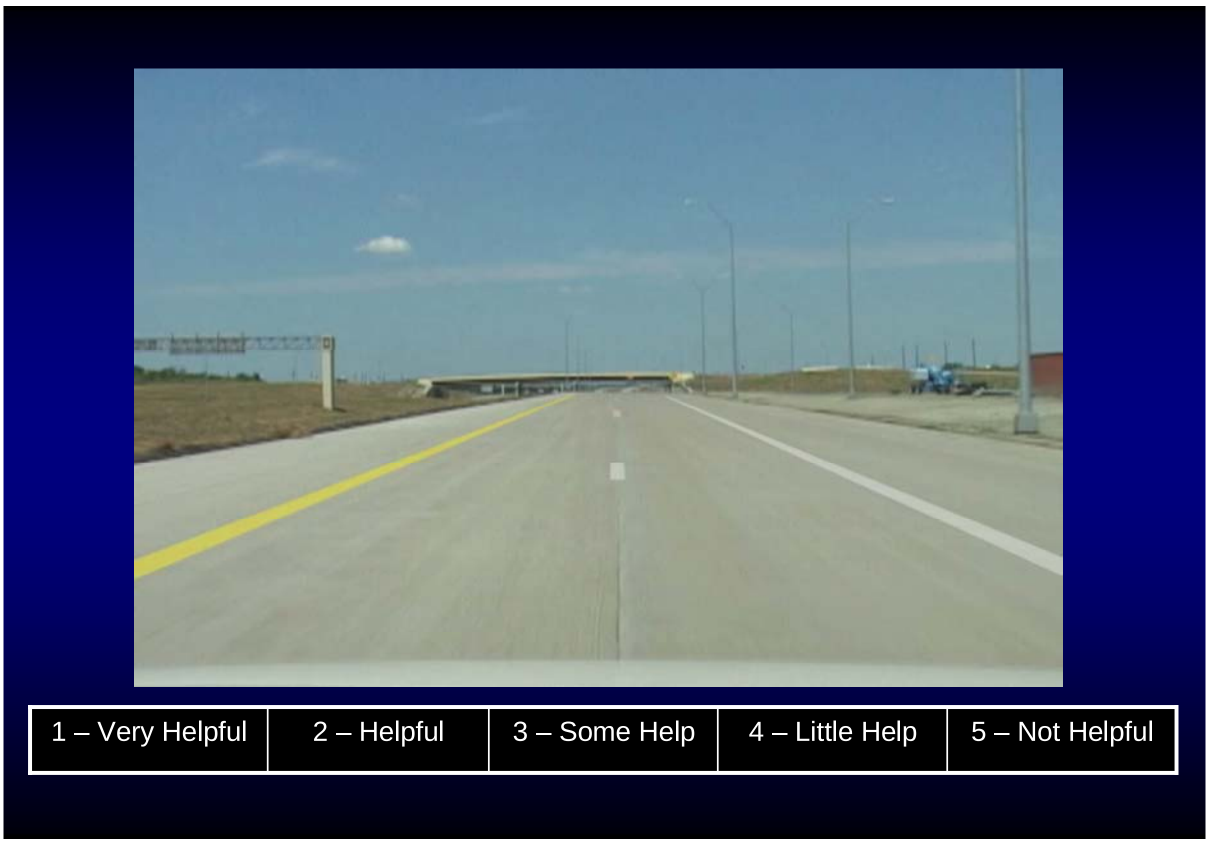


Figure 28. Rating Sample Screen Shot.

Screen shots of each of the treatments were then presented to each test subject for ranking in the third task. Each subject was instructed to place the screen shots in a decreasing order of preference with the first marking as the best and the last marking as the worst. This format further avoided biasing any one marking because the screen shots were made into individual laminated cards that could be randomly shuffled prior to presenting them to the test subjects. It was believed that while the data should not be biased by the order in which the treatments would be presented, that only the first and last treatments selected (best and worst, respectively) would be the most representative of the test subjects' true preferences in favor or against the treatments. In other words, it was thought that the test subjects' middle rankings would be far more guessing than a true ranking of preference. Subsequently, the ranking data would be used to supplement the data from the ratings task, and in particular, be used to break any ties.

The last task consisted of closing questions that further investigated the driver understanding of contrast markings and any changes in preferences to contrast markings after completing the rating and ranking tasks. It should also be noted that the subjects' comments were recorded throughout the tasks to capture any other useful information that may not directly pertain to a particular task. The data were tabulated, frequencies were generated from the data, and the general comments were used to further analyze the data.

Two versions of the laptop survey were created to minimize error associated with the order in which the treatments were presented. One version of the laptop survey is in Appendix D.

Laptop Survey Results

There were a total of 128 test subjects from 4 different major cities in Texas. There was an even distribution of 32 participants from each of the cities (Dallas, Houston, San Antonio, El Paso). Every attempt was made to obtain an even distribution between the following demographic categories: age, education, and driver experience. Figure 29 contains a breakdown of the demographics associated with the test subjects. The age group distribution was well balanced, but the education and driver experience distributions were not as well balanced, with only 2 percent not completing a high school level of education, and only 5 percent with less than 6 years of driving experience. It should be noted that all of the drivers who did not complete a high school level of education had 6 years or more of driving experience.

Some additional questions were asked to assess driver experience with contrast markings prior to the rating and ranking tasks. A sample of a bordered contrast marking, the most frequently used contrast marking used in the state of Texas and the United States, was used to ask whether test subjects had seen contrast markings before. It was found that only 53 percent of the test subjects believed they had seen contrast markings prior to taking part in this survey.

test subjects that had previously seen contrast markings were evenly distributed amongst the test subjects. The test subjects were also asked whether they believe contrast markings would be considered helpful when driving, and it was found that 71 percent believed they might be helpful. This question was also asked at the close of the study, and 74 percent of the test subjects then believed that contrast markings would be helpful. The portion of test subjects that did not find the contrast markings helpful had problems with accepting a marking for which the meaning was not clear.

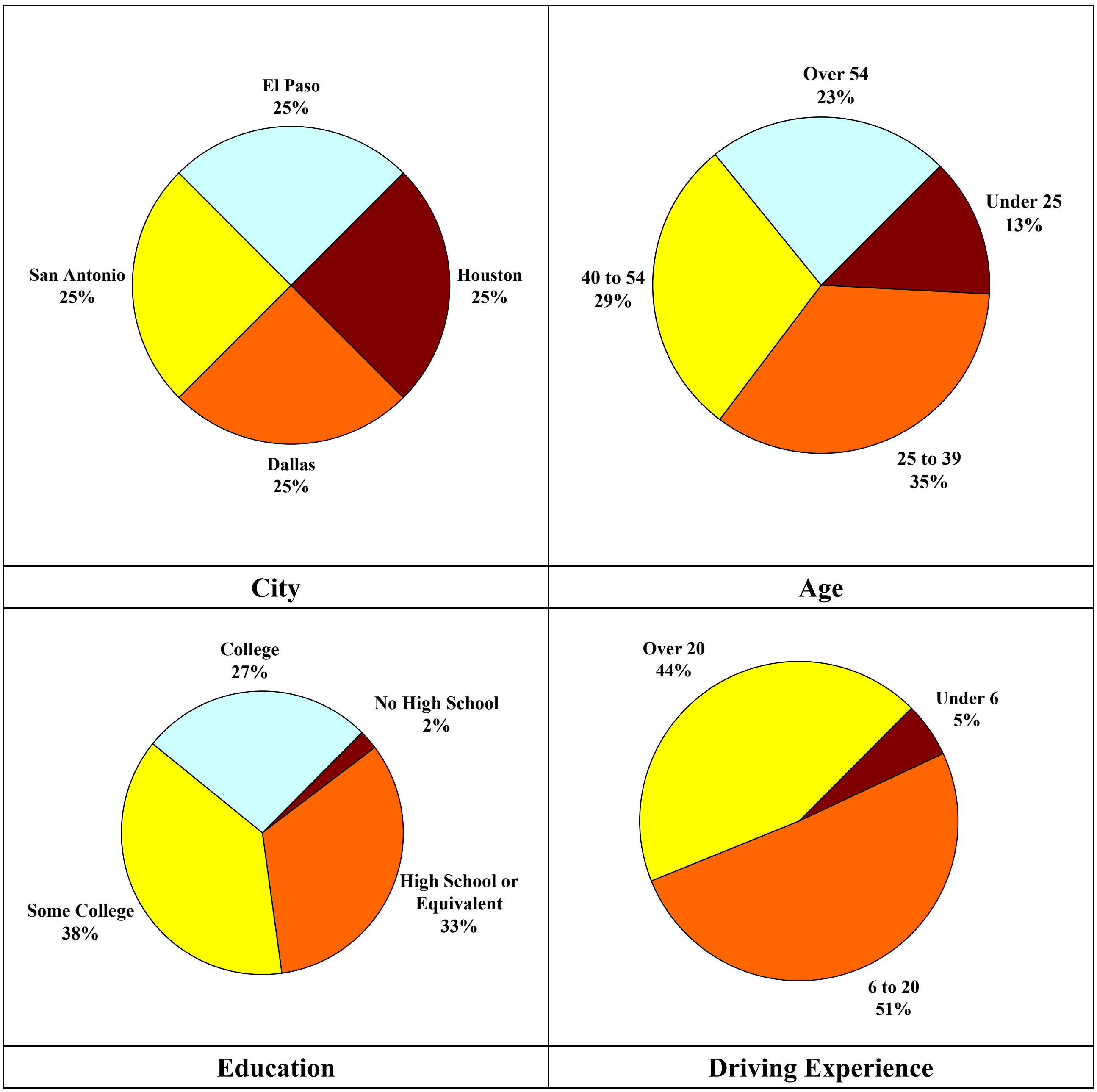


Figure 29. Demographics.

Comments with respect to the test subjects' opinions of each of the markings and their overall interpretation of the meaning of the black marking were recorded and categorized. The majority (38 percent) of the test subjects believed the black marking was intended to make the white stand out more, or highlight the white. About 19 percent believed that the black markings had the same meaning as the white markings, and were intended to contrast with the pavement to separate the lanes of travel. Approximately 24 percent were unsure of the meaning of the black, and the remaining responses fell into multiple other categories. All of the general interpretations of the meaning of the black marking are listed below. The last four in particular are somewhat alarming and may need additional consideration.

- Same as white (19 percent)
- Highlight white (38 percent)
- Not sure (24 percent)
- Other (7 percent)
    - Out of white paint
    - Heavy traffic
    - Pass with caution
    - New pavement
    - Keep you alert
    - Change in traffic flow
    - Construction
- Center of lane (1 percent)
- Do not pass/Do not cross (10 percent)
- Two-way traffic (1 percent)
- Stop (1 percent)

The preference data from the rating and rankings tasks were tabulated into frequencies for analysis. As stated previously, two different laptop surveys were generated to minimize bias associated with the order in which treatments were presented to the test subjects in the ratings task. Hence, the first analysis focused on establishing whether there was any bias between the data from the two different versions of the surveys. The sample size, mean, and standard deviations for each treatment for each survey were calculated and a t-test was used to assess whether the mean values were statistically different. It was found that none of the responses to the 10 treatments were statistically different between the two different surveys when assuming a 95 percent level of confidence. Subsequently, the data from the surveys were collapsed for further analyses.

Again, the preference data were obtained through two tasks. The first was a rating of each of the 10 treatments in isolation. The second was a ranking task where the subjects ranked all 10 treatments in order of preference.

The researchers analyzed the ratings of each option by calculating the mean response of all participants. The overall highest rated marking was the standard 4-inch marking (with an average score of 2.0). The next highest rated marking designs, in order, were: the bordered marking (2.3), the 8-inch white marking (2.5), and then the lag-shadow marking (2.7). All other marking designs had a mean rating of 2.8 or 2.9.

The results from the task in which the participants took all 10 options and ranked them by preference were analyzed by developing a weighted score using the overall rankings and then assigning a multiplier to each rank order. For each participant, his/her ordered ranking was assigned a number from 1 to 10 (1 being his/her preferred option). Then the ranking preferences were summed. Rankings with a 1 were weighted by 10, rankings with a 2 were weighted by 9, and so on. Similar to the rating results, the 4-inch marking was ranked most preferred in the ranking task, with an overall weighted score of 851. The second highest ranking score was the continuous black overlaid with skips with a score of 810. The third highest ranking was the 8-inch white markings, with a weighted score of 754. The bordered markings, which were the highest rated contrast pattern in the previous task, were ranked seventh with a score of 694. And the lag-shadow marking, which was also scored high in the rating task, was ranked last with a score of 467.

There are some interesting trends in the data worth noting. For instance, some markings were ranked heavily on each end of the scale (i.e., participants either strongly preferred them or strongly opposed them) while some markings were mostly ranked with centered results, indicating perhaps that the participants had no strong preference. For instance, the 6-inch white marking was ranked sixth overall with a weighted score of 695. However, it was also the most preferred marking and the most opposed marking. About 29 percent of the participants ranked it as the best option while 33 percent ranked it the very worst option. On the other hand, marking designs such as the bordered pattern and the 4-inch white next to the 4-inch black were seldom ranked as being most or least preferred.

The overall preference results show that there are some consistencies within the rating and ranking tasks, but just as evident are inconsistencies in the results. For both preference tasks, the 4-inch white marking was most preferred. This is however confounded with the fact that this is the most familiar marking of all 10 treatments shown. The highest rated contrast pattern was the bordered design, which may be related to the fact that 43 percent of the contrast markings in Texas are the same pattern. The highest ranked contrast pattern was the continuous design, but this was also the most confusing treatment (i.e., participants provided the most negative verbal responses to this treatment). Furthermore, some of the participants felt this marking indicated “do not cross.”

CONTRAST MARKING SUMMARY

Two different types of surveys were used to assess the current state-of-the-practice with respect to the use of contrast markings, and to assess driver understanding and preference with respect to the design of contrast markings. The state-of-the-practice survey was conducted using an online internet survey and it was sent to the individual districts within the state of Texas, and to traffic engineers for the departments of transportation for the other 49 states within the United States. The driver understanding and preference survey was completed using an innovative laptop survey that combined digitally edited video and still images of 10 different pavement marking treatments that included one 4-inch wide standard white marking, two wider white markings, and seven different contrast markings.

The results of the online contrast pavement marking survey have provided insight into this area of pavement markings. Comparing the results of previous surveys to this one clearly indicates an increasing use of contrast markings in the United States, 22 percent in 2002 versus 64 percent in 2006. In TxDOT districts, 64 percent say they currently use contrast markings and 79 percent say they plan to use them in the future, further indicating the increase in usage. Contrast marking usage seems to be increasing on PCC surfaces, but these markings have not been used much on faded asphalt surfaces.

The TxDOT districts and states both feel that contrast markings increase safety by providing better contrast on PCC road surfaces, although no statistical data are available to support this position. The most commonly used marking type was a tape contrast marking. The most commonly used design was the bordered design, which is a design that is unique to tape products and is applied to the roadway the same way standard tape is. The lead and lag designs were also common due to being easier to implement and maintain than other non-tape designs.

The online surveys indicated that some public questions arise as to why the black marks are used. This would indicate that the driving public may not necessarily know the meaning of the black portion of the markings and may interpret them in a way other than they are intended. The results of the laptop survey confirmed this confusion. There were a number of different comments associated with the meaning of contrast markings.

The results of the laptop survey indicated a driver preference toward the bordered contrast marking, which is a tape product. This preference matches with the current state-of-the-practice with 43 and 47 percent of the districts in Texas and the states in the United States implementing this design if they use contrast markings, respectively. The shadow (lead or lag) and continuous designs were the most preferred non-tape contrast designs. The shadow (lead or lag) designs are also used frequently throughout Texas and across the United States. However, the continuous design is only used in one state, and it produced more confusing comments than any other design tested.

Furthermore, when considering the initial cost of installation and long-term maintenance of non-tape contrast markings, the shadow design, whether lead or lag, is most economical to install and maintain. The difference in the initial cost of the markings between more economical marking materials and tapes can be as much as 10 times; however, tape products are used on PCC, in areas of high ADT, and come with long warranties.

CHAPTER 5: SUMMARY AND RECOMMENDATIONS

SUMMARY

A number of findings were discovered through the completion of the research described above. In addition, Phase I of the research provided additional discoveries, some of which were only preliminary but helped shape the focus for Phase II. The summary provided below was developed to capture all of the findings related to this research effort and therefore includes Phase I findings as appropriate.

Findings from the Visibility Study

- The overall mean nighttime rainfall rate over a 20-year period in Texas is about 0.40 in/hr. About 88 percent of the rainfall events produced rainfall intensities of less than 0.75 in/hr.
- Rain conditions are an infrequent nighttime occurrence, as a rain event occurs during less than 1 percent of the total nighttime hours.
- Dry retroreflective measurements have a strong correlation with detection distance (0.85 to 0.75). Wet retroreflective measurements have a weaker correlation with detection distance (0.70 to 0.40). Dry retroreflectivity measurements cannot be used to estimate or predict wet retroreflectivity measurements.
- The wetting rate associated with ASTM E2176 ranges from 6 in/hr up to 14 in/hr with a median value of 9.3 in/hr. These wetting rates are higher than the vast majority of rainfall intensities that will be realized in actual conditions. It has been reported in ASTM committee discussions that these wetting rates are needed to compensate for the transmissivity of 30 meters of rainfall. However, wetting rates at such levels flood the markings.
- Generally, retroreflectivity measurements decrease as the wetting rate is increased.
- Not all wetting techniques are equal. Many variables impact the results including but not limited to the following: cross slope at measurement location, water flow rate, wind, droplet size, droplet density, uniformity of water sprayed, and interference with the instrument measuring window. This makes it difficult to compare continuous wetting

retroreflectivity measurements made with different setups or in different conditions. The researchers found significant differences in wet retroreflectivity measurements for samples measured using the indoor spray setup compared to the values using the outdoor rain tunnel.

- Previous studies have found a positive correlation between ASTM E2176 continuous wetting retroreflectivity measurements and detection distances. While the results shown herein produced similar findings, it was also shown that as the rate of continuous wetting increases, so do the correlation levels associated with detection distance. The findings produced herein also showed weaker correlations than those previously reported. The researchers attribute this to the fact that a broad range of materials were used in this study, which had not been the case previously.
- Previous studies have used a small number of pavement marking samples but have always included at least one material with a high continuous wetting retroreflectivity level (over 300 mcd/m^2/lx). These studies have reported strong correlations between ASTM E2176 continuous wetting retroreflectivity measurements and detection distances. However, most conventional markings measure less than 250 mcd/m^2/lx under ASTM E2176 continuous wetting conditions. Therefore, relationships including any of the few markings that measure over 300 mcd/m^2/lx under continuous wetting retroreflectivity provide an unrepresentative relationship between the measured marking retroreflectivity and expected performance under nighttime rainfall conditions (when frequency of use is not considered). The findings summarized here show that when only the conventional markings are used in the analyses, the correlation rates drop substantially (0.70 versus 0.40).
- There was no continuous wetting rate that provided retroreflectivity measurements that resulted in significantly higher correlation rates than other continuous wetting rates (compared to detection distances). The strength of the correlations was not improved even when the continuous wetting rate to measure retroreflectivity and the rainfall rate used to measure detection distance were the same.
- RRPMs have the longest wet-night detection distance of any other marking tested. The average detection distance of the RRPMs was over 550 ft, which was over 200 ft longer than the longest average detection distance for any of the other markings tested.

- Besides RRPMs, a newly available tape from 3M provided the longest wet-night detection distances under both the low and high rainfall rates (206 ft and 187 ft, respectively). In comparison, thermoplastic with Type III beads performed reasonably well within the group of non-structured markings. The detection distances measured under both the low and high rainfall rates were 183 ft and 155 ft, respectively. The benefit of the larger Type III bead was again revealed in Phase II (as it was in Phase I) when thermoplastic with Type II beads resulted in some of the substantially shorter detection distances (171 ft and 128 ft, respectively). It should be noted that the impact of heavier rain and small beads was again revealed by the Phase II results—the 128 ft detection distance for thermoplastic and Type II beads under the higher rainfall rate was the shortest detection distance of all markings studied in Phase II.
- Various rumble stripe designs consisting of different spacings (12 inches and 24 inches on center) and different bead types (Type II and Type III) were compared versus their flat line counterparts. It was found that rumble stripes appear to improve wet-night performance when Type II beads are used. However, when Type III beads are used there is no apparent benefit in terms of maximum detection distance.
- No conclusive benefits were found when the marking width was increased to 6-inch over the standard 4-inch width. The results of five pairs of markings were tested under dry and wet conditions. In addition, an interaction between research participants and wider lines was also explored, but to no avail.
- Most markings provide wet-night detection distances in the range of 140 to 200 ft.

Findings from the Cost-Effectiveness Study

- Generally, thermoplastic pavement markings do not perform as well on Portland cement concrete surfaces as they do on asphalt surfaces. Polyurea may be a viable alternative as it has displayed better performance on concrete, but costs twice as much. Tape products are another option that should be considered for PCC surfaces but may be cost prohibitive.
- Tape products are expensive but have several advantages: they can perform well in high AADT situations on PCC surfaces, they can provide greater visibility than other

markings in both wet and dry conditions, they typically are warranteed by the manufacturer, and they can be purchased as a contrast marking.

- When considering wet and dry visibility, the most cost-effective system is spray applied thermoplastic with supplemental RRPMs.

Findings from the Contrast Marking Study

- Contrast marking usage is increasing in the United States, 22 percent of states in 2002 versus 64 percent in 2006. In TxDOT districts, 64 percent say they currently use contrast markings, and 79 percent say they plan to use them in the future.
- Contrast marking usage seems to be increasing on PCC surfaces, but has not been used much on faded asphalt surfaces.
- The TxDOT districts and other states both feel that contrast markings increase safety by providing better contrast on PCC road surfaces.
- Contrast marking tape was the most common material used even though it is the most expensive. The bordered design was the most commonly used design. This design was found to be unique to tape products and is applied to the roadway the same way standard tape is. The lead and lag designs were also common due to being easier to implement and maintain than some of the other designs.
- Public feedback has indicated that questions arise as to the purpose of the black markings. Responses to the laptop survey also indicated confusion as to the purpose of the black markings and confusion with some of the design types.
- The results of the laptop survey indicated a driver preference toward the bordered contrast marking.

RECOMMENDATIONS

The following recommendations were developed based on the findings described above as well as current knowledge about TxDOT policy and currently available pavement marking technologies, including standards and specifications for wet-night retroreflectivity measurements.

- Because wet retroreflectivity measurements made in accordance with ASTM specifications are unreliable and have displayed weak correlation to performance, because wet-night detection distances of RRPMs far exceed any markings, even the most technologically advanced markings available on the market today, and because it is currently the policy of TxDOT to use RRPMs on all state roadways, the researchers recommend that TxDOT continue to use RRPMs as its wet-night delineation treatment and avoid specifying marking performance based on ASTM wet retroreflective standard measurement procedures. This recommendation is further supported through the cost-effectiveness analysis, which shows:

  - The cost of installing and maintaining RRPMs is about $75 per mile at 80 foot spacing.
  - The cost of installing and maintaining the standard thermoplastic pavement markings is $475 per mile. The RRPMs would supplement this application.
  - The cost of installing and maintaining the best wet-performing pavement marking is $3300 per mile.
  - Therefore, from a cost and visibility point-of-view, installing and maintaining RRPMs and a standard thermoplastic marking is much more effective than just using a wet-weather product in most situations.

- In terms of contrast markings, the researchers recommend using the bordered or lead/lag shadow designs when using contrast markings. These options allow for a standard tape product, which may be considered effective on PCC surfaces with high AADTs, and a non-tape product for other applications. While the installation costs of these two options can vary considerably, they will help provide consistency across the state for the drivers.
- In addition, the researchers recommend the following suggestions:
  - In their waterborne paint and thermoplastic applications, TxDOT should use Type III beads for added wet-night detection distances. However, it is important to add enough binder thickness to the waterborne specification to hold a Type III bead because of the larger bead diameter.
  - TxDOT should consider using more mixed beads installations that include high refractive index beads.
  - TxDOT should install and monitor long-line test decks in multiple locations to monitor the performance of materials over time.

- More research is needed on wider markings. This research was conducted to determine the maximum detection distance and showed no conclusive benefit to wider markings. However, there may be other benefits such as short range peripheral vision used for lane keeping tasks.
- Educational efforts should be developed to help drivers understand the meaning of contrast markings.
- Finally, a follow-up study should be conducted to assess the relationship between safety and pavement marking retroreflectivity, particularly under wet-nighttime conditions.

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APPENDIX A:
PAVEMENT MARKING SAMPLES

Table A1. Pavement Marking Information.

Marking Number: 5		**Marking Number:** 6	
Binder Type: Waterborne Paint		**Binder Type:** Waterborne Paint	
Manufacturer: Ennis Paint		**Manufacturer:** All-American Coatings	
Bead: Type III Weissker		**Bead:** Type II Potters	
Marking: Width: 3.8 in. Thickness: 0.01 in.		**Marking:** Width: 4.0 in. Thickness: 0.02 in.	
Marking Number: 8		**Marking Number:** 10	
Binder Type: LS90 Polyurea		**Binder Type:** LS50 Epoxy	
Manufacturer: EpoPlex		**Manufacturer:** EpoPlex	
Bead: GloMarc 90, Type II Visibead		**Bead:** Type III (25% Visionglow, 75% Visibead)	
Marking: Width: 4.3 in. Thickness: 0.017 in.		**Marking:** Width: 4.1 in. Thickness: 0.02 in.	
Marking Number: 11		**Marking Number:** 12	
Binder Type: Thermoplastic		**Binder Type:** Thermoplastic	
Manufacturer: Ennis Paint		**Manufacturer:** Ennis Paint	
Bead: Type I, III, High Index		**Bead:** Type I, III, High Index	
Marking: Width: 4.3 in. Thickness: 0.11 in.		**Marking:** Width: 6.0 in. Thickness: 0.11 in.	
Marking Number: 13		**Marking Number:** 14	
Binder Type: Methyl Methacrylate		**Binder Type:** Methyl Methacrylate	
Manufacturer: Ennis Paint		**Manufacturer:** Ennis Paint	
Bead: Type I		**Bead:** Type I	
Marking: Width: 5.8 in. Thickness: 0.11 in.		**Marking:** Width: 4.3 in. Thickness: 0.16 in.	

Table A2. Pavement Marking Information (Continued).

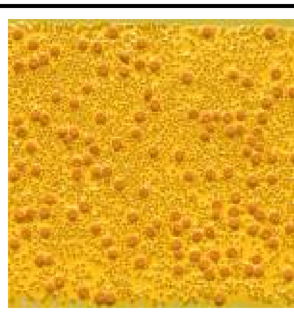
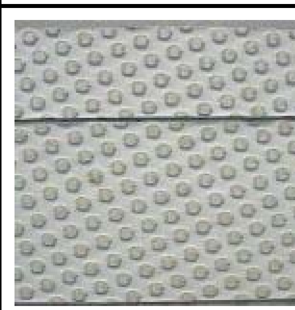
Marking Number: 15 **Binder Type:** Tape A380I **Manufacturer:** 3M **Marking:** Width: 4.0 in. Thickness: 0.02 in.		**Marking Number:** 16 **Binder Type:** Tape A750ES **Manufacturer:** 3M **Marking:** Width: 4.0 in. Thickness: 0.01 in.	
Marking Number: 17 **Binder Type:** Tape 380WR **Manufacturer:** 3M **Marking:** Width: 4.0 in. Thickness: 0.02 in.		**Marking Number:** 18 **Binder Type:** Tape ATM 400 **Manufacturer:** Advanced Traffic Markings **Marking:** Width: 4.0 in. Thickness: 0.06 in.	
Marking Number: 19 **Binder Type:** Inverted Profile Thermoplastic (Diamond) **Manufacturer:** Ennis Paint **Bead:** Type I **Marking:** Width: 4.3 in Thickness: 0.16 in.		**Marking Number:** 20 **Binder Type:** Methyl Methacrylate **Manufacturer:** Ennis Paint **Bead:** Type I **Marking:** Width: 4.3 in. Thickness: 0.16 in.	
Marking Number: 21 **Binder Type:** Tape A380I **Manufacturer:** 3M **Marking:** Width: 4.0 in. Thickness: 0.02 in.		**Marking Number:** 22 **Binder Type:** Tape A750ES **Manufacturer:** 3M **Marking:** Width: 4.0 in. Thickness: 0.01 in.	
Marking Number: 23 **Binder Type:** LS90 Polyurea **Manufacturer:** EpoPlex **Bead:** GloMarc 90, Type II Visibead **Marking:** Width: 4.0 in. Thickness: 0.017 in.		**Marking Number:** 24 **Binder Type:** Tape 380WR **Manufacturer:** 3M **Marking:** Width: 6.0 in. Thickness: 0.02 in.	

Table A3. Pavement Marking Information (Continued).

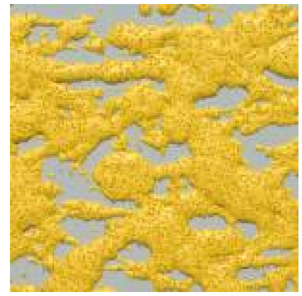
Marking Number: 25 **Binder Type:** Tape ATM 400 **Manufacturer:** Advanced Traffic Markings **Marking:** Width: 4.0 in. Thickness: 0.06 in.		**Marking Number:** 31 **Binder Type:** Methyl Methacrylate **Manufacturer:** Degussa **Bead:** Type III Virgin Swarco **Marking:** Width: 4.5 in. Thickness: 0.12 in.	
Marking Number: 32 **Binder Type:** Thermoplastic **Manufacturer:** Dobco **Bead:** Type III **Marking:** Width: 4.6 in. Thickness: 0.07 in.		**Marking Number:** 33 **Binder Type:** Thermoplastic **Manufacturer:** Ennis Paint **Bead:** Flexolite M247, Visibead E16 **Marking:** Width: 4.1 in. Thickness: 0.09 in.	
Marking Number: 34 **Binder Type:** Thermoplastic **Manufacturer:** Ennis Paint **Bead:** Type II **Marking:** Width: 3.9 in. Thickness: 0.06 in.		**Marking Number:** 35 **Binder Type:** Rumble Stripe: Thermoplastic **Manufacturer:** Ennis Paint **Bead:** Type II **Marking:** Width: 3.9 in. Thickness: 0.06 in.	
Marking Number: 37 **Binder Type:** Thermoplastic **Manufacturer:** Ennis Paint **Bead:** Type II **Marking:** Width: 5.6 in. Thickness: 0.05 in.		**Marking Number:** 38 **Binder Type:** Thermoplastic **Manufacturer:** Ennis Paint **Bead:** Type II **Marking:** Width: 4 in. Thickness: 0.07 in.	
Marking Number: 39 **Binder Type:** Thermoplastic **Manufacturer:** Dobco **Bead:** Type III **Marking:** Width: 4.5 in. Thickness: 0.07 in.		**Marking Number:** 40 **Binder Type:** Thermoplastic **Manufacturer:** Dobco **Bead:** Type III **Marking:** Width: 5.6 in. Thickness: 0.06 in.	

Table A4. Pavement Marking Information (Continued).

Marking Number: 41 **Binder Type:** Rumble Stripe: Thermoplastic **Manufacturer:** Dobco **Bead:** Type III **Marking:**Width: 4.5 in. Thickness: 0.07 in.		**Marking Number:** 42 **Binder Type:** Rumble Stripe: Thermoplastic **Manufacturer:** Dobco **Bead:** Type III **Marking:**Width: 4.5 in. Thickness: 0.07 in.	
Marking Number: 43 **Binder Type:** Inverted Profile Thermoplastic (Transverse) **Manufacturer:** Ennis **Bead:** Type I, Type III **Marking:**Width: 4.3 in. Thickness: 0.26 in.		**Marker Number:** 36 **Binder Type:** RRPM Type II C-R **Manufacturer:** Avery Dennison **Marking:**Width: 3.6 in. Thickness: 0.6 in.	

APPENDIX B:
JMP VISIBILITY ANALYSIS OUTPUT

Table B1. JMP Output for Model A on SqrtDetect.

Response SqrtDetect
Summary of Fit

RSquare	0.789735
RSquare Adj	0.784497
Root Mean Square Error	1.490515
Mean of Response	14.98936
Observations (or Sum Wgts)	2634

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Pavement Marking	**17**	**17**	**2536**	**34.4867**	**<.0001**
Glare	**1**	**1**	**2539**	**188.4432**	**<.0001**
Flow	**2**	**2**	**2540**	**1726.842**	**0.0000**
Age	**1**	**1**	**32.71**	**5.0016**	**0.0323**
Vision Group	**1**	**1**	**32.66**	**5.2558**	**0.0285**
LocnCode	**8**	**8**	**2537**	**191.0741**	**<.0001**
Flow*Pavement Marking	**34**	**34**	**2536**	**7.3298**	**<.0001**

Note: Significant effects are shown in **bold**.

Pavement Marking
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
8	15.123058	0.27634502	15.8267404	228.706872
11	14.261176	0.27316092	14.9096193	203.381135
12	14.630571	0.27349767	15.6691179	214.053613
13	14.444260	0.26733312	14.670584	208.636642
14	14.242628	0.27113797	15.376805	202.85245
17	15.423438	0.27392260	16.3580177	237.882425
19	14.616820	0.27644270	15.6942237	213.65144
20	15.122630	0.27648108	15.8294984	228.69393
24	15.844667	0.26393704	16.4249324	251.053473
34	13.339171	0.28814297	14.1284765	177.933486
35	13.972729	0.26631885	14.7128576	195.237145
37	13.384941	0.27358168	13.9629466	179.156647
38	13.283441	0.26228677	13.9899189	176.449794
39	14.130122	0.29045661	15.3088499	199.660349
40	13.568141	0.26640450	14.0135674	184.094461
41	13.803932	0.26236714	14.4708337	190.548541
42	13.669740	0.26280238	13.9676417	186.861795
43	14.610275	0.26338883	15.1047828	213.460143

Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	13.901569	0.24113550	14.7099134	193.253611
Y	14.706402	0.24126588	15.2761123	216.278271

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	12.590762	0.24501301	12.7055506	158.527281
L	13.518797	0.24438134	13.6681595	182.757877
O	16.802398	0.24158255	17.1273068	282.320567

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	13.769402	0.35211554	14.1209989	189.596428
Y	14.838569	0.32392508	15.5416569	220.183135

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	13.724234	0.40241937	13.9617887	188.3546
B	14.883737	0.28389546	15.4448676	221.525627

Level	**Flow = O**			**Flow = L**			**Flow = H**		
Pavement Marking	Least Sq Mean	Std Error	Pred Mean	Least Sq Mean	Std Error	Pred Mean	Least Sq Mean	Std Error	Pred Mean
8	19.25392	0.312973	370.7136	13.60833	0.358754	185.1865	12.50692	0.349898	156.4232
11	17.53758	0.308435	307.5668	13.20567	0.331351	174.3897	12.04027	0.359025	144.9682
12	17.50718	0.30245	306.5014	13.29598	0.350254	176.783	13.08856	0.350103	171.3103
13	16.64898	0.314119	277.1886	13.81223	0.321283	190.7777	12.87157	0.322134	165.6773
14	16.11668	0.284606	259.7473	13.85351	0.344929	191.9198	12.7577	0.353477	162.7588
17	17.84526	0.290052	318.4532	14.62845	0.359619	213.9917	13.7966	0.350942	190.3462
19	17.89022	0.304397	320.0598	13.55846	0.358944	183.8319	12.40179	0.358788	153.8043
20	18.13101	0.313321	328.7334	13.91135	0.35218	193.5257	13.32553	0.355602	177.5698
24	18.25754	0.291748	333.3378	15.12266	0.314539	228.695	14.1538	0.324672	200.3299
34	16.29066	0.337111	265.3855	12.35441	0.366213	152.6314	11.37245	0.39961	129.3326
35	16.24958	0.286285	264.0488	12.80597	0.324348	163.993	12.86263	0.33766	165.4474
37	15.40814	0.302317	237.4107	13.27001	0.341935	176.0933	11.47667	0.35876	131.714
38	15.13474	0.286034	229.0605	12.74655	0.311548	162.4744	11.96903	0.321413	143.2577
39	16.25451	0.323552	264.2091	13.543	0.398496	183.4127	12.59286	0.39351	158.5801
40	15.85261	0.309469	251.3054	13.27352	0.322828	176.1863	11.57829	0.317191	134.0568
41	15.83458	0.28456	250.7339	13.15801	0.319522	173.1331	12.41921	0.315437	154.2368
42	15.47111	0.302462	239.3554	13.11133	0.306162	171.9068	12.42678	0.314749	154.4249
43	16.75886	0.300489	280.8593	14.07892	0.314632	198.216	12.99305	0.312208	168.8193

Table B2. JMP Output for SqrtDetect Under Wet Conditions.

Response SqrtDetect
Summary of Fit

RSquare	0.707445
RSquare Adj	0.69796
Root Mean Square Error	1.24598
Mean of Response	13.20028
Observations (or Sum Wgts)	1434

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Pavement Marking	**17**	**17**	**1357**	**22.8022**	**<.0001**
Glare	**1**	**1**	**1357**	**65.9842**	**<.0001**
Flow	**1**	**1**	**1360**	**201.0292**	**<.0001**
Age	1	1	31.08	2.4252	0.1295
Vision Group	1	1	31.08	3.7862	0.0608
LocnCode	**7**	**7**	**1358**	**50.9547**	**<.0001**
Flow*Pavement Marking	**17**	**17**	**1357**	**1.9314**	**0.0126**

Note: Significant effects are shown in **bold**.

Effect Details
Pavement Marking
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
8	12.789887	0.29964942	12.7853177	163.581211
11	12.488797	0.29585294	12.7698387	155.97004
12	13.153612	0.29748566	13.4328946	173.017519
13	13.155510	0.28640424	13.2863998	173.06743
14	13.218682	0.29704755	13.7657384	174.733547
17	14.004465	0.30072166	14.1139384	196.125028
19	12.947009	0.30114725	13.2418555	167.625031
20	13.512165	0.29954422	13.6726317	182.578612
24	14.536455	0.28536383	14.7590528	211.308521
34	11.768620	0.31241092	12.0980753	138.500419
35	12.701541	0.28995202	12.8973965	161.329147
37	12.185359	0.29763857	12.202379	148.482971
38	12.251219	0.28407640	12.6129628	150.092366
39	12.987004	0.31811912	13.6635533	168.662274
40	12.324891	0.28550160	12.5651182	151.902943
41	12.637854	0.28442076	12.7824675	159.715348
42	12.665791	0.28192678	13.0022698	160.42227
43	13.476455	0.28313417	13.7983176	181.614834

Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	12.665872	0.26030829	12.9279488	160.424305
Y	13.201386	0.26022767	13.4651204	174.276581

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	12.442335	0.26078175	12.7055506	154.811703
L	13.424922	0.26019223	13.6681595	180.228533

Age

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	12.531786	0.37548973	12.5519089	157.045669
Y	13.335471	0.35423292	13.6694149	177.834783

Vision Group

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	12.405437	0.42967531	12.2412934	153.894856
B	13.461821	0.30992789	13.644546	181.220615

Table B3. Tukey's Multiple Comparison Test for Flow*Pavement Marking LS Means Differences.

Level																Least Sq Mean	Pred Dist
L,24	A															15.098981	227.979224
L,17	A	B														14.342943	205.720026
L,43		B	C													14.147260	200.144966
H,24		B	C	D												13.973929	195.270688
L,20		B	C	D	E											13.844616	191.6734
L,13		B	C	D	E	F										13.670229	186.875156
H,17		B	C	D	E	F	G									13.665986	186.759165
L,14		B	C	D	E	F	G									13.597354	184.888026
L,39		B	C	D	E	F	G	H	I	J						13.528286	183.014511
L,19		B	C	D	E	F	G	H								13.514732	182.647973
L,12		B	C	D	E	F	G	H	I							13.421483	180.136208
L,8		B	C	D	E	F	G	H	I	J	K					13.314883	177.286121
L,40		B	C	D	E	F	G	H	I	J	K					13.222632	174.837999
H,20		B	C	D	E	F	G	H	I	J	K					13.179714	173.704872
L,11			C	D	E	F	G	H	I	J	K					13.145278	172.798341
L,37				D	E	F	G	H	I	J	K					13.067204	170.751808
L,41				D	E	F	G	H	I	J	K					13.007799	169.202832
L,42					E	F	G	H	I	J	K					13.000644	169.016744
L,35					E	F	G	H	I	J	K	L				12.918664	166.891879
H,12				D	E	F	G	H	I	J	K	L	M			12.885742	166.04234
H,14					E	F	G	H	I	J	K	L	M			12.840010	164.865853
H,43					E	F	G	H	I	J	K	L				12.805650	163.984662
L,38							G	H	I	J	K	L	M			12.666019	160.428038
H,13							G	H	I	J	K	L	M	N		12.640790	159.789577
H,35								H	I	J	K	L	M	N		12.484418	155.860699
H,39						F	G	H	I	J	K	L	M	N	O	12.445723	154.896009
H,19								H	I	J	K	L	M	N	O	12.379285	153.246709
H,42										J	K	L	M	N	O	12.330939	152.052048
H,41											K	L	M	N	O	12.267909	150.501583
H,8									I	J	K	L	M	N	O	12.264891	150.427544
L,34											K	L	M	N	O	12.139591	147.369665
H,38													M	N	O	11.836419	140.100813
H,11												L	M	N	O	11.832315	140.003674
H,40															O	11.427150	130.579763
H,34														N	O	11.397649	129.906411
H,37															O	11.303514	127.769435

Levels not connected by same letter are significantly different.

Table B4. JMP Output for Model B Applied on SqrtDetect.

Response SqrtDetect
Summary of Fit

RSquare	0.69767
RSquare Adj	0.432191
Root Mean Square Error	1.246598
Mean of Response	14.01467
Observations (or Sum Wgts)	784

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**732.2**	**32.1031**	**<.0001**
Flow	**1**	**1**	**734.4**	**148.1433**	**<.0001**
Age	1	1	31.05	2.7864	0.1051
Vision Group	1	1	31.12	3.0989	0.0882
Width	1	1	732.4	1.0165	0.3137
Pair	**4**	**4**	**732.4**	**58.9263**	**<.0001**
LocnCode	**7**	**7**	**733.5**	**27.1275**	**<.0001**
Pair*Width	**4**	**4**	**732.4**	**5.5441**	**0.0002**

Note: Significant effects are shown in **bold**.

Table B5. JMP Output for Pavement Marking Pair 11 (Wet).

Response SqrtDetect
Pair=11
Summary of Fit

RSquare	0.7713
RSquare Adj	0.7499
Root Mean Square Error	1.317
Mean of Response	13.09
Observations (or Sum Wgts)	141

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**105.3**	**5.3062**	**0.0232**
Flow	**1**	**1**	**100.7**	**15.3993**	**0.0002**
Age	**1**	**1**	**32.24**	**4.6056**	**0.0395**
Vision Group	1	1	31.31	3.3108	0.0784
Width	**1**	**1**	**97.98**	**7.1619**	**0.0087**
LocnCode	**7**	**7**	**104.7**	**3.1462**	**0.0047**

Note: Significant effects are shown in **bold**.

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	12.5325	0.3437	12.9226438	157.063763
Y	13.1003	0.3432	13.2542252	171.616666

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	12.3173	0.3460	12.4391892	151.715353
L	13.3155	0.3437	13.6458916	177.302116

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	12.1208	0.4679	12.1993419	146.913676
Y	13.5120	0.4435	13.788302	182.573266

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	12.201566	0.5336	12.0917369	148.878217
B	13.431197	0.3862	13.5274528	180.39704

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	12.5031	0.3410	12.7698387	156.326714
6	13.1297	0.3415	13.4328946	172.388878

Table B6. JMP Output for Pavement Marking Pair 11 (Dry).

Response SqrtDetect Pair=11
Summary of Fit

RSquare	0.790082
RSquare Adj	0.766972
Root Mean Square Error	1.25085
Mean of Response	17.83482
Observations (or Sum Wgts)	122

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**79.49**	**20.2200**	**<.0001**
Age	1	1	31.17	2.0661	0.1606
Vision Group	1	1	30.6	0.0995	0.7546
LocnCode	**8**	**8**	**90.03**	**20.0172**	**<.0001**
Width	1	1	83.31	1.2387	0.2689

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	17.572857	0.30420290	17.4124439	308.805287
Y	18.613682	0.30914866	18.285842	346.469165

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	17.706861	0.42885512	17.1763846	313.532931
Y	18.479678	0.34920351	18.1442125	341.498485

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	18.004681	0.46497658	17.7080231	324.168537
B	18.181858	0.32077761	17.87991	330.579951

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	18.239737	0.32282539	17.6027914	332.688001
6	17.946802	0.30289519	18.0451053	322.087697

Table B7. JMP Output for Pavement Marking Pair 13 (Wet).

Response SqrtDetect Pair=13
Summary of Fit

RSquare	0.7818
RSquare Adj	0.7646
Root Mean Square Error	1.0866
Mean of Response	13.487
Observations (or Sum Wgts)	165

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**121.3**	**14.8784**	**0.0002**
Flow	**1**	**1**	**127.9**	**15.7776**	**0.0001**
Age	**1**	**1**	**30.65**	**4.5355**	**0.0413**
Vision Group	1	1	30.39	1.8091	0.1886
Width	1	1	120.8	0.0003	0.9873
LocnCode	**7**	**7**	**127.2**	**8.6889**	**<.0001**

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	12.9565	0.2854	13.1169873	167.870966
Y	13.6224	0.2836	13.8522575	185.568969

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	12.874118	0.29565768	13.2052975	165.742905
L	13.704755	0.28530619	13.7583479	187.82032

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	12.7171	0.3912	12.6329225	161.724454
Y	13.8618	0.3720	14.1006112	192.148946

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	12.9098	0.4503	12.6898334	166.663314
B	13.6691	0.3217	13.8333796	186.843157

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	13.2880	0.2892	13.7657384	176.570563
6	13.2909	0.2825	13.2863998	176.647687

Table B8. JMP Output for Pavement Marking Pair 13 (Dry).

Response SqrtDetect Pair=13
Summary of Fit

RSquare	0.816502
RSquare Adj	0.799693
Root Mean Square Error	1.10768
Mean of Response	16.81164
Observations (or Sum Wgts)	144

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**105.4**	**26.2508**	**<.0001**
Age	1	1	32.4	2.7651	0.1060
Vision Group	**1**	**1**	**31.18**	**4.4179**	**0.0437**
LocnCode	**8**	**8**	**108.8**	**20.5391**	**<.0001**
Width	**1**	**1**	**108**	**7.1445**	**0.0087**

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	16.022106	0.26821664	16.52749	256.707879
Y	17.035528	0.26909468	17.1204889	290.209215

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	16.111063	0.37697636	16.069483	259.566347
Y	16.946571	0.33001471	17.2311126	287.186271

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	15.980745	0.41650951	15.8428146	255.384204
B	17.076889	0.29545567	17.2520083	291.620143

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	16.245402	0.26002860	16.5983829	263.913082
6	16.812232	0.28224292	17.1777856	282.651148

Table B9. JMP Output for Pavement Marking Pair 17 (Wet).

Response SqrtDetect Pair=17
Summary of Fit

RSquare	0.8146
RSquare Adj	0.7998
Root Mean Square Error	1.1071
Mean of Response	14.503
Observations (or Sum Wgts)	164

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**125.6**	**6.4733**	**0.0122**
Flow	**1**	**1**	**125**	**27.8310**	**<.0001**
Age	1	1	31.74	0.1758	0.6779
Vision Group	**1**	**1**	**31.31**	**4.6043**	**0.0398**
Width	**1**	**1**	**121.4**	**7.2294**	**0.0082**
LocnCode	**7**	**7**	**126.4**	**11.4505**	**<.0001**

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	14.0593	0.3140	14.1855296	197.663093
Y	14.5428	0.3147	14.8135461	211.493274

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	13.785144	0.31458426	13.965243	190.030191
L	14.816935	0.31586612	15.0158665	219.541569

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	14.1780	0.4321	14.0247666	201.014267
Y	14.4241	0.4066	14.8687505	208.055498

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	13.6408	0.4932	13.4595174	186.071662
B	14.9613	0.3545	14.948138	223.83961

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	14.0473	0.3234	14.1139384	197.326447
6	14.5548	0.3046	14.7590528	211.84179

Table B10. JMP Output for Pavement Marking Pair 17 (Dry).

Response SqrtDetect Pair=17
Summary of Fit

RSquare	0.849202
RSquare Adj	0.836808
Root Mean Square Error	1.338106
Mean of Response	18.34548
Observations (or Sum Wgts)	159

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**115.2**	**45.9665**	**<.0001**
Age	1	1	31.89	1.7037	0.2011
Vision Group	**1**	**1**	**30.33**	**6.5365**	**0.0158**
LocnCode	**8**	**8**	**125.4**	**46.1422**	**<.0001**
Width	**1**	**1**	**117.1**	**4.3737**	**0.0387**

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	17.738414	0.29611507	17.8164631	314.651347
Y	19.204540	0.29809319	18.9232231	368.814363

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	18.105114	0.42078330	17.5024627	327.795136
Y	18.837841	0.36560377	18.8564003	354.864256

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	17.729157	0.45888803	17.7290638	314.322993
B	19.213798	0.33344730	18.6450474	369.170034

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	18.222646	0.29992038	18.158822	332.064814
6	18.720309	0.30252846	18.5393181	350.449967

Table B11. JMP Output for Pavement Marking Pair 37 (Wet).

Response SqrtDetect Pair=37
Summary of Fit

RSquare	0.7544
RSquare Adj	0.7357
Root Mean Square Error	1.2832
Mean of Response	12.45
Observations (or Sum Wgts)	171

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	1	1	128	0.2848	0.5945
Flow	**1**	**1**	**129.8**	**30.1541**	**<.0001**
Age	1	1	30.11	2.2497	0.1441
Vision Group	1	1	30.15	2.3577	0.1351
Width	1	1	127.1	0.0461	0.8303
LocnCode	**7**	**7**	**131.8**	**6.7889**	**<.0001**

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	12.1042	0.3281	12.3177508	146.510837
Y	12.2124	0.3286	12.5770789	149.142745

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	11.5802	0.3340	11.736043	134.101666
L	12.7363	0.3250	13.062495	162.214356

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	11.6918	0.4506	11.773746	136.698564
Y	12.6248	0.4306	12.9904446	159.384344

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	11.6556	0.5201	11.5178616	135.853826
B	12.6609	0.3726	12.8915047	160.29921

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	12.1360	0.3219	12.6129628	147.283043
6	12.1805	0.3360	12.202379	148.365672

Table B12. JMP Output for Pavement Marking Pair 37 (Dry).

Response SqrtDetect Pair=37
Summary of Fit

RSquare	0.835352
RSquare Adj	0.821138
Root Mean Square Error	1.158871
Mean of Response	15.69925
Observations (or Sum Wgts)	152

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**112.2**	**33.3443**	**<.0001**
Age	**1**	**1**	**30.9**	**5.6856**	**0.0234**
Vision Group	1	1	31.38	3.0869	0.0887
LocnCode	**8**	**8**	**118**	**25.0740**	**<.0001**
Width	**1**	**1**	**111.7**	**5.2749**	**0.0235**

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	14.899962	0.27990730	15.196398	222.008878
Y	16.044709	0.28135945	16.2579819	257.432699

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	14.847345	0.39653892	14.7382197	220.443647
Y	16.097327	0.34354469	16.2598566	259.123935

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	14.987611	0.43951399	14.7762625	224.628494
B	15.957060	0.31131181	16.0633693	254.627776

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	15.231606	0.27559847	15.6015835	232.001828
6	15.713066	0.28961803	15.8335498	246.900428

Table B13. JMP Output for Pavement Marking Pair 39 (Wet).

Response SqrtDetect Pair=39
Summary of Fit

RSquare	0.8168
RSquare Adj	0.7999
Root Mean Square Error	1.0831
Mean of Response	12.911
Observations (or Sum Wgts)	143

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	1	1	101.5	11.8630	0.0008
Flow	1	1	103.4	49.9011	<.0001
Age	1	1	32.95	2.1614	0.1510
Vision Group	1	1	32.42	3.2521	0.0806
Width	1	1	104.7	3.3911	0.0684
LocnCode	7	7	106.9	2.6282	0.0152

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	12.2823	0.3087	12.5483585	150.855793
Y	12.9220	0.3083	13.2783052	166.977596

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	11.8593	0.3111	12.3250292	140.64249
L	13.3450	0.3137	13.5389757	178.090069

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	12.1753	0.4256	12.1377553	148.238064
Y	13.0290	0.4007	13.4083585	169.75516

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	12.0531	0.4860	11.9672957	145.277586
B	13.1512	0.3497	13.3301058	172.954129

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	12.8132	0.3359	13.6635533	164.17857
6	12.3911	0.2942	12.5651182	153.539339

Table B14. JMP Output for Pavement Marking Pair 39 (Dry).

Response SqrtDetect Pair=39
Summary of Fit

RSquare	0.853922
RSquare Adj	0.834659
Root Mean Square Error	1.28516
Mean of Response	16.67573
Observations (or Sum Wgts)	104

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**71.29**	**5.5941**	**0.0207**
Age	1	1	36.77	3.5109	0.0689
Vision Group	1	1	32.54	0.9650	0.3332
LocnCode	**8**	**8**	**80.25**	**28.1708**	**<.0001**
Width	1	1	83.78	1.8631	0.1759

Effect Details
Glare
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
N	15.905135	0.32478528	16.4346011	252.973319
Y	16.529401	0.33242117	16.9463795	273.221112

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	15.690284	0.46718336	16.1130023	246.185007
Y	16.744253	0.34798671	16.8730467	280.369995

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	15.931731	0.49411510	15.6344456	253.820039
B	16.502806	0.32555142	17.0228214	272.342602

Width
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
4	16.428225	0.35241295	16.8841339	269.88659
6	16.006311	0.32362967	16.5038836	256.201992

Table B15. JMP Output for Rumble Stripe Analysis for Pavement Marking Pair 34.

Response SqrtDetect Rumble Stripes=34 (Pair 1)
Summary of Fit

RSquare	0.602618
RSquare Adj	0.563849
Root Mean Square Error	1.349308
Mean of Response	12.59765
Observations (or Sum Wgts)	136

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**94.39**	**5.4595**	**0.0216**
Age	1	1	34.7	3.6929	0.0629
Vision Group	1	1	29.38	3.7769	0.0616
LocnCode	7	7	112.3	1.2408	0.2866
Flow	**1**	**1**	**101**	**6.4581**	**0.0126**
Number of Rumbles	**1**	**1**	**119.4**	**6.3748**	**0.0129**

Table B16. Least Squares Means Table for Number of Rumbles for Pavement Marking Pair 34.

Level	Least Sq Mean	Std Error	Mean	Pred Dist
0	11.9002	0.3034	12.0980753	141.614022
1	12.6595	0.2492	12.8973965	160.262814

Table B17. JMP Output for Rumble Stripe Analysis for Pavement Marking Pair 39.

Response SqrtDetect Rumble Stripes=39 (Pair 2)
Summary of Fit

RSquare	0.713817
RSquare Adj	0.698631
Root Mean Square Error	1.250795
Mean of Response	13.03145
Observations (or Sum Wgts)	259

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**215.2**	**17.6138**	**<.0001**
Age	1	1	31.55	0.9404	0.3395
Vision Group	**1**	**1**	**31.5**	**4.2999**	**0.0464**
LocnCode	**7**	**7**	**220.1**	**9.6176**	**<.0001**
Flow	**1**	**1**	**216.6**	**23.3991**	**<.0001**
Number of Rumbles	2	2	216.3	1.7627	0.1740

Table B18. JMP Output for Rumble Stripe Analysis for Pavement Markings 35 versus 41.

Response SqrtDetect Rumble Stripes=35 and 41 (Pair 3)
Summary of Fit

RSquare	0.6948
RSquare Adj	0.6737
Root Mean Square Error	1.2364
Mean of Response	12.835
Observations (or Sum Wgts)	186

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Glare	**1**	**1**	**144.6**	**9.8734**	**0.0020**
Flow	**1**	**1**	**147.6**	**6.6685**	**0.0108**
Age	1	1	31.33	3.7928	0.0605
Vision Group	**1**	**1**	**31.71**	**5.2341**	**0.0290**
LocnCode	**7**	**7**	**153.3**	**6.7910**	**<.0001**
Bead Type	1	1	144.9	0.0044	0.9471

Table B19. JMP Output for Car 1 versus Car 2 Analysis.

Response SqrtDetect
Summary of Fit

RSquare	0.726096
RSquare Adj	0.712486
Root Mean Square Error	1.238549
Mean of Response	13.62691
Observations (or Sum Wgts)	339

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age	1	1	63.83	1.1564	0.2863
Vision Group	**1**	**1**	**61.71**	**4.2066**	**0.0445**
Flow	**1**	**1**	**299.8**	**31.2498**	**<.0001**
Retroreflectivity MX30	1	1	275.2	1.1127	0.2924
Pavement Marking	**4**	**4**	**274.9**	**5.4972**	**0.0003**
LocnCode	**7**	**7**	**277.8**	**11.8930**	**<.0001**
CAR	1	1	77.69	1.9952	0.1618

Table B20. JMP Output for Car 1 versus Car 3 Analysis.

Response SqrtDetect
Summary of Fit

RSquare	0.721749
RSquare Adj	0.707525
Root Mean Square Error	1.196803
Mean of Response	13.35361
Observations (or Sum Wgts)	330

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age	1	1	62.2	2.9867	0.0889
Vision Group	**1**	**1**	**59.27**	**4.3414**	**0.0415**
Flow	**1**	**1**	**297.1**	**28.0855**	**<.0001**
Retroreflectivity MX30	1	1	270.2	0.3373	0.5619
Pavement Marking	**4**	**4**	**268.2**	**5.8012**	**0.0002**
LocnCode	**7**	**7**	**271.4**	**9.9010**	**<.0001**
CAR	**1**	**1**	**79.9**	**10.9676**	**0.0014**

Effect Details

CAR
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
1	13.622010	0.25249091	14.0372227	185.559164
3	12.534346	0.22754397	12.6699977	157.109842

Table B21. JMP Output for Car 2 (Glare On, More Illumination) Analysis.

Response SqrtDetect
Glare=Y
Summary of Fit

RSquare	0.802287
RSquare Adj	0.792209
Root Mean Square Error	1.51601
Mean of Response	15.27611
Observations (or Sum Wgts)	1300

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Pavement Marking	**17**	**17**	**1205**	**18.1050**	**<.0001**
Flow	**2**	**2**	**1207**	**953.8199**	**<.0001**
Age	1	1	31.75	2.4255	0.1293
Vision Group	**1**	**1**	**31.69**	**5.2337**	**0.0290**
LocnCode	**8**	**8**	**1205**	**113.8933**	**<.0001**
Flow*Pavement Marking	**34**	**34**	**1205**	**3.6893**	**<.0001**

Effect Details
Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	12.833853	0.25225910	12.95827	164.707794
L	13.769668	0.25071273	13.9356712	189.603766
O	17.322370	0.24555573	17.573828	300.06452

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	14.268080	0.35194626	14.6192392	203.578095
Y	15.015849	0.32780116	15.7098331	225.475709

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	14.062677	0.40227866	14.3516032	197.758897
B	15.221251	0.28716070	15.6944656	231.686474

Table B22. JMP Output for Car 3 (Glare Off, Less Illumination) Analysis.

Response SqrtDetect
Glare=N
Summary of Fit

RSquare	0.809413
RSquare Adj	0.799958
Root Mean Square Error	1.391595
Mean of Response	14.70991
Observations (or Sum Wgts)	1334

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Pavement Marking	**17**	**17**	**1238**	**18.7515**	**<.0001**
Flow	**2**	**2**	**1241**	**854.6216**	**<.0001**
Age	**1**	**1**	**32.87**	**6.9834**	**0.0125**
Vision Group	**1**	**1**	**32.81**	**4.7459**	**0.0367**
LocnCode	**8**	**8**	**1238**	**90.5527**	**<.0001**
Flow*Pavement Marking	**34**	**34**	**1238**	**4.4627**	**<.0001**

Effect Details

Flow
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
H	12.311448	0.24650187	12.4506462	151.571753
L	13.208839	0.24556357	13.3880154	174.473425
O	16.236724	0.24042135	16.719242	263.631194

Age
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
O	13.295258	0.34794947	13.6129314	176.763898
Y	14.542749	0.31995017	15.3824284	211.491536

Vision Group
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
A	13.375076	0.39746998	13.5710094	178.892667
B	14.462931	0.28055222	15.2046631	209.176365

Table B23. JMP Output for Car 2 (Glare On, More Illumination) Analysis Under the Dry Condition.

Response SqrtDetect Glare=Y, Flow=O
Summary of Fit

RSquare	0.832725
RSquare Adj	0.824438
Root Mean Square Error	1.23211
Mean of Response	17.57383
Observations (or Sum Wgts)	573

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Pavement Marking	**17**	**17**	**516.9**	**32.2452**	**<.0001**
Age	1	1	30.01	1.5939	0.2165
Vision Group	**1**	**1**	**30.03**	**5.2308**	**0.0294**
LocnCode	**8**	**8**	**517.3**	**188.9954**	**<.0001**

Effect Details
Pavement Marking
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
8	20.046916	0.33228169	19.7888627	401.878852
11	18.423259	0.31761993	18.0011897	339.41648
12	18.340554	0.30838788	18.5429473	336.375913
13	17.079917	0.32677451	17.3070645	291.723582
14	16.684050	0.28407623	17.01448	278.357521
17	18.777355	0.29294252	18.6603521	352.589066
19	19.019584	0.31396235	18.7346227	361.744567
20	19.094755	0.32462464	18.8871927	364.609662
24	19.186806	0.29432737	19.186094	368.133521
34	17.099077	0.35561266	17.1267131	292.378427
35	17.356665	0.28492049	17.1979292	301.253835
37	16.202918	0.30780026	16.3202587	262.53454
38	15.821780	0.28716541	16.2108946	250.328713
39	16.724146	0.34179717	17.1867352	279.697045
40	16.147507	0.31967426	16.7505341	260.741975
41	16.426274	0.28384856	16.6738604	269.822468
42	16.391657	0.30822479	16.0821923	268.686419
43	17.488859	0.30795670	17.6440636	305.860176

Table B24. JMP Output for Car 3 (Glare Off, Less Illumination) Analysis Under the Dry Condition.

Response SqrtDetect Glare=N, Flow=O
Summary of Fit

RSquare	0.817819
RSquare Adj	0.809607
Root Mean Square Error	1.214129
Mean of Response	16.71924
Observations (or Sum Wgts)	627

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Pavement Marking	17	17	570	30.0379	<.0001
Age	1	1	31.55	6.2561	0.0178
Vision Group	1	1	31.63	3.2022	0.0831
LocnCode	8	8	570.4	137.4434	<.0001

Effect Details
Pavement Marking
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean	Pred Dist
8	18.901843	0.31497592	19.2467918	357.279673
11	17.407298	0.31561590	17.2309531	303.014032
12	17.179987	0.30781640	17.5774355	295.151959
13	16.428428	0.32053048	17.0623581	269.893251
14	15.658768	0.28511817	16.2088451	245.197011
17	17.363989	0.29081199	17.7156093	301.508127
19	17.216462	0.30801656	17.6298378	296.406578
20	17.739791	0.32142654	17.9972229	314.700198
24	17.966452	0.29563072	17.9248809	322.79339
34	16.248892	0.35783651	16.3077629	264.026504
35	15.939702	0.28782736	15.767438	254.074109
37	14.978280	0.30768832	15.3763384	224.348873
38	14.775153	0.28431428	15.0700568	218.305132
39	15.793169	0.33309584	16.6178447	249.424186
40	15.570811	0.31477192	16.2818981	242.450153
41	15.711882	0.28526424	16.0366169	246.863224
42	15.312276	0.30827129	15.2869132	234.46579
43	16.451960	0.30353590	16.887084	270.666976

Table B25. Least Squares Means Table for CAR (Car 1 versus Car 2).

Level	Least Sq Mean	Std Error	Mean	Pred Dist
1	13.660739	0.29423470	14.0372227	186.615801
2	13.129960	0.26053579	13.2378207	172.39586

APPENDIX C:
ONLINE CONTRAST PAVEMENT MARKING SURVEY

Hello: You are invited to participate in our survey on contrast pavement markings associated with TxDOT Research Project 0-5008. Through this survey, we are contacting each TxDOT district (state) and are asking them to answer some questions about contrast pavement markings. It will take less than 15 minutes to complete the survey. Your participation in this study is greatly appreciated. Please answer all of the questions to the best of your knowledge. If you are not the appropriate person in your district (state) to answer the questions please forward the e-mail to the appropriate individual.

If you have questions at any time about the survey or the procedures, you may contact Adam Pike at 979-862-4591 or by email at a-pike@tamu.edu. Please complete the survey within 30 days. Thank you very much for your time.

Please start the survey by clicking on the Continue button below.

Are you familiar with the term contrast marking? (Please see description and pictures below)

Yes

No

Contrast markings are standard longitudinal pavement markings that have a black marking applied around, next to, before, or after them. The black marking is used to provide increased contrast with light colored pavements, such as faded asphalt and Portland cement concrete. See images below for a few examples.

Does your district (state) currently use contrast markings, or have they been used in the past?

Yes

No

Why does your district (state) use contrast markings?

To improve safety

Public has requested them

Trial/experimental

Other districts have used them

Other ___________________________________

Are there any set criteria for contrast marking implementation? If yes, please indicate them in the box below.

Yes

No

On what specific roads have contrast markings been used? Please indicate roadway classification, ADT, and road surface type.

What type of contrast pavement marking material has your district (state) used? Select all that apply.

Paint

Tape

Plural Component (Polyurea, Epoxy, etc)

Thermoplastic

Other ___________________________________

Is there a specific reason why you use this (these) materials? Select all that apply.

Cost

Experimental

Past Performance

Installation Parameters (temperature, installation time, availability)

Other ___________________________________

Below are seven illustrations of different contrast pavement marking designs. Please note that these designs only show a two skip/lane line application of the markings with the direction of travel indicated. Please select the designs that are currently used in your district (state). Select all that apply.

A: Continuous Black

B: Lag/Shadow

C: Lead

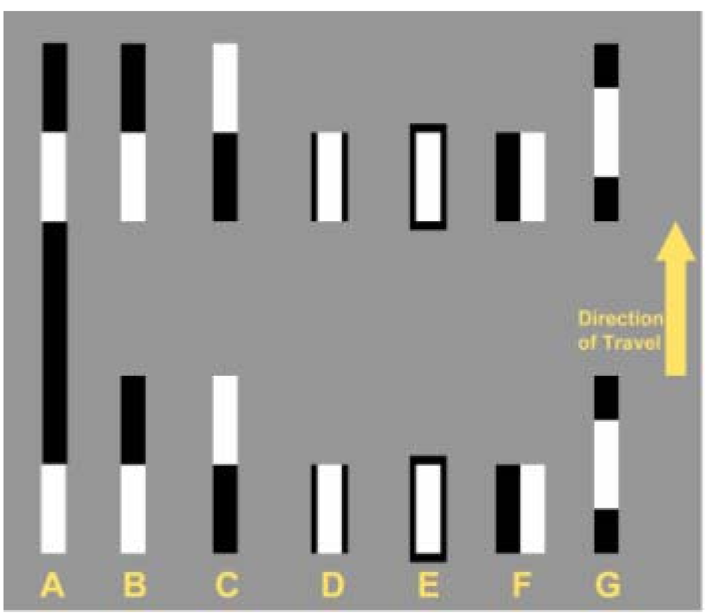
D: Bordered

E: Boxed

F: Side by Side

G: Half Lead, Half Lag

Other ___________________________________



How are the contrast markings applied to the roadway?

Single Truck Application

Multiple Truck Application

Other ___________________________________

Please indicate your basic procedures for contrast pavement marking installation for each type of contrast marking that you use.

How are contrast markings reapplied after they have been in service? Please indicate the basic procedure for reapplication of contrast markings.

What is the cost to install contrast markings? (i.e., actual installation cost based on marking type if multiple types are implemented, and/or increased cost as compared to just using white or yellow markings.)

Have you experienced any problems in regard to installing contrast markings?

Have you experienced any problems in regard to reapplying or restriping contrast markings?

Have you experienced any durability issues with the contrast pavement markings as compared to standard pavement markings? (i.e., does the black pavement marking fail before the white marking, or does the black marking cause the white marking to fail sooner than if the black marking was not present?)

If your district (state) uses multiple marking materials or multiple designs, what are the pros and cons of each? (i.e., cost, installation, durability, maintenance.)

	Yes	No	N/A
Has your district (state) received any public feedback or comments on contrast markings?	❑	❑	❑
Has the public shown a favorable response to currently installed contrast markings?	❑	❑	❑
Has the public requested that contrast markings be installed or for increased usage of contrast markings?	❑	❑	❑

Does your district (state) plan on installing contrast markings in the future?

Yes

No

Please add the reasoning behind your answer to the previous question in the box below.

This is the last page of the survey. Please fill in the contact information and answer the last few questions. Thank you for taking the time to complete our survey.

Name:

Title:

District (State):

E-mail Address:

Phone Number:

Do you have any additional comments or suggestions related to our research efforts?

Would it be ok if we contact you again if we have any further questions?

Yes

No

Would you like us to transmit our findings to you when the final report has been published?

Yes

No

APPENDIX D:
LAPTOP CONTRAST MARKING SURVEY

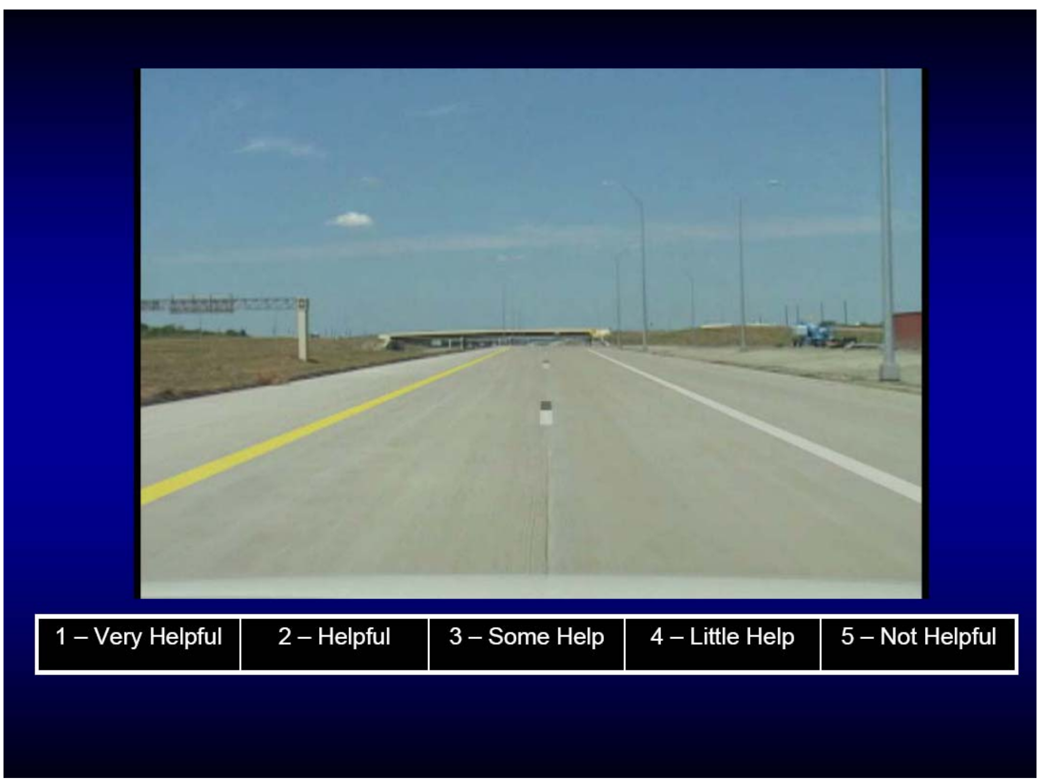
Rating 1


1 – Very Helpful
2 – Helpful
3 – Some Help
4 – Little Help
5 – Not Helpful

Rating 2


1 – Very Helpful
2 – Helpful
3 – Some Help
4 – Little Help
5 – Not Helpful

Rating 3


1 – Very Helpful
2 – Helpful
3 – Some Help
4 – Little Help
5 – Not Helpful

Rating 4

1 – Very Helpful	2 – Helpful	3 – Some Help	4 – Little Help	5 – Not Helpful


Rating 5


1 – Very Helpful
2 – Helpful
3 – Some Help
4 – Little Help
5 – Not Helpful

Rating 6

1 – Very Helpful	2 – Helpful	3 – Some Help	4 – Little Help	5 – Not Helpful

Rating 7

1 – Very Helpful	2 – Helpful	3 – Some Help	4 – Little Help	5 – Not Helpful

Rating 8


1 – Very Helpful
2 – Helpful
3 – Some Help
4 – Little Help
5 – Not Helpful

Rating 9

1 – Very Helpful	2 – Helpful	3 – Some Help	4 – Little Help	5 – Not Helpful

Rating 10

1 – Very Helpful	2 – Helpful	3 – Some Help	4 – Little Help	5 – Not Helpful

Ranking

Final Questions

- After viewing all of the different pavement markings, what do you think the black means?
- Did you find the contrast markings to be helpful?
- Do you have any additional questions or comments?
- Thank you, for your participation.