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PAVEMENT MARKING VISIBILITY REQUIREMENTS DURING WET NIGHT CONDITIONS

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Supplementary Notes

Abstract

This study investigated the performance of pavement markings in wet night conditions. Typically, performance will decrease in wet conditions. The degradation is a result of flooding of the marking optics and a change in the optical media, thereby reducing retroreflectivity and the visibility distance. Several technologies are available to improve the visibility of markings under wet conditions.

This study used four technologies and evaluated them in a dynamic situation. In the experiment, vehicles were driven by older participants and visibility was measured based on the detection distances of the beginning or ending of a continuous edge marking. The results indicate that a specifically designed wet retroreflective tape performed better than the currently used paint and glass bead technology. Paint with large glass beads and profiled thermoplastics also showed an improvement over the standard paint and glass bead technology.

A relationship between retroreflectivity and the detection distance was found, which was used to postulate a minimum required value for visibility during wet night conditions. A value of 200 mcd/m2/lx appears to provide a reasonable detection distance for a minimum performance requirement.

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ABSTRACT

This study investigated the performance of pavement markings in wet night conditions. Typically, performance will decrease in wet conditions. The degradation is a result of flooding of the marking optics and a change in the optical media, thereby reducing retroreflectivity and the visibility distance. Several technologies are available to improve the visibility of markings under wet conditions.

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INTRODUCTION

The pavement marking technologies currently in use in the Commonwealth of Virginia are typically not effective in wet night conditions. In dry night conditions, the light emitted from vehicle headlamps is retro-reflected back to the driver by optical elements, typically glass beads, in the surface of the pavement markings. In wet conditions, these conventional optical elements can become covered with a film of water. In these wet conditions, the amount of light that reflects back to the driver is reduced through a change in the indices of refraction between the optical elements and the surrounding medium and through light scatter, where light is reflected in all directions and only a small portion of light is returned back to the light source. Therefore, the visibility of the markings, which is a result of the retroreflectivity, is greatly reduced. The reduction in visibility then decreases the driver's ability to safely use the markings as tracking information.

The concerns about the effectiveness of pavement markings in wet conditions have been discussed for many years. In 1997, the Virginia Department of Transportation (VDOT) sponsored a customer service survey conducted by Coopers and Lybrand, in which more than 3,000 Virginians were asked to rate their satisfaction with seven aspects of Virginia's transportation system. "Nighttime visibility, especially in wet conditions" was identified as a great concern for survey participants and thus needed further research. This issue, which has been discussed a number of times by the Traffic Research Advisory Committee of the Virginia Transportation Research Council (VTRC), is also of particular concern to VDOT's Traffic Engineering Division and Materials Divisions due to the degradation of the retroreflectivity.

Snow-plowable raised pavement markers are currently used by VDOT to provide wet night retroreflectivity and may be viewed as a benchmark for performance in wet night conditions. Although these markers appear to be effective, they provide roadway delineation at points as opposed to the continuous delineation provided by highly performing pavement marking system. A comparison of pavement markings and markers, the quality of wet night retroreflectivity, and the cost-effectiveness was paramount to VDOT in determining a strategy for providing improved wet night visibility.

To this end, a project entitled "Wet Night Visibility of Pavement Markings" was conducted by the Virginia Tech Transportation Institute (VTTI) and sponsored by VTRC and the Federal Highway Administration (FHWA) [1]. The project reviewed the effectiveness of six different wet night visible pavement marking technologies in rain conditions. The testing was performed statically with the observers in parked vehicles counting skip marks as a measure of visibility distance. The results of this investigation showed that some of the technologies, particularly materials that had a profiled surface, provided a benefit in visibility distance over standard paint and glass beads. The project also demonstrated that the American Society for Testing and Materials (ASTM) test methods show a relationship to the visibility of the pavement markings in wet conditions.

The current project is a continuation of the first and was undertaken to further test four of these marking technologies in a dynamic condition. This report presents the results from this continued study.

PURPOSE AND SCOPE

The purpose of this project was to establish drivers' visibility needs under dynamic wet conditions. During the testing, participants drove a vehicle at the test facility through a simulated rain condition. The driver was asked to perform a series of tasks, which included establishing the visibility distance of the pavement markings. The experimental design included overhead lighting, glare conditions, recovery testing, two different vehicle types, and four different pavement marking types.

The analysis of the experimental results from the dynamic testing was undertaken with the goal of developing a description of the motorists' needs under all of the tested rain conditions and during the recovery (drying) period after a rainfall.

The final step was the development of performance specifications for pavement markings in wet night conditions. These specifications result from the visibility distance measurements made during static and dynamic testing.

METHODS AND MATERIALS

The dynamic experimental phase of the project included four of the pavement marking technologies from the static experiment and was performed under two specific lighting conditions and with two different types of experimental vehicles. For each of the experimental materials, a series of evaluations were conducted in phases. Each of these phase comparisons were then combined for an overall analysis which compared of all of the materials. The initial set of tasks evaluated the performance of specific pavement marking technologies in a rainfall condition. These were followed by an evaluation during the recovery (drying phase) of each marking type. The recovery phase occurred immediately after the cessation of rain, followed by an evaluation of each marking type during dry conditions.

Experimental Design

The experimental design is a 4 (Pavement Marking Type) by 2 (Lighting: On, Off) by 2 (Glare: On, Off) by 2 (Pavement Type: Concrete, Asphalt) by 2 (Vehicle Type: Sedan, Truck) factorial design. The conditions are described in Table 1.

Table 1. Experimental Design for Saturated Condition

Factor	Levels
Pavement Marking	Standard Paint with Regular Beads Standard Paint with Large Beads Wet Retroreflective Tape Thermoplastic Profile-Type Markings
Overhead Lighting	On Off
Discomfort Glare	Present Absent
Pavement Type	Asphalt Concrete
Vehicle Type	Sedan Truck

In addition to the primary experimental setup, a secondary target detection task was also used which required participants to detect traffic cones that were placed in the center of the roadway, close to one of the detection locations. This secondary task provided two specific additions to the experimental setup. First, participants were required to increase their vigilance during the task in order to detect both the roadway markings and the traffic cones. Secondly, detecting traffic cones, which were placed on the skip marks between each lane, encouraged participants to increase their horizontal scanning pattern, in an effort to mimic a "normal" scanning at night. This secondary visual search task (i.e., traffic-cone detection) was implemented after initial pilot testing of the primary task revealed participants were limiting their search behavior to the right edge or only to the shoulder edge markings.

During three of the intermediate sessions a supplemental detection task was also created. For this task, participants were asked to identify when they could detect a pavement marking that was placed in a specific location on the Virginia Smart Road. The pavement marking was changed to vary the width. This aspect of the project was undertaken to utilize the participants time while the road was being set up for the next experimental condition. The data from this experiment are documented in another report (e.g., see Gibbons, McElheny, and Edwards (2006)[2]).

Independent Variables

The five independent variables in the experimental design were provided through the functionality of the Smart Road, experimental vehicles, and through the application of different types of pavement markings.

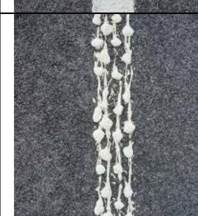
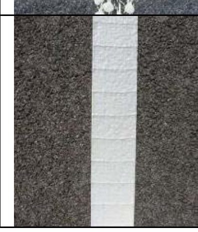
The primary independent variable was the pavement marking material, which was selected from the initial experiment to provide the widest range of marking retroreflectivity possible (see Table 2). It's important to note that only the white edge lines were used in this investigation; the yellow centerline was a standard VDOT material and was not part of the detection task.

In order to perform the testing, the marking materials were installed on the road serially leading to four intermediate testing sessions. This means that the first material was installed, all of the testing was completed, this material was removed, and then the next material was then installed and tested. This cycle was performed for all four of the material types. After each material installation, the material was allowed to weather for a period of 4 weeks. During this time the retroreflectivity was monitored. For analysis purposes, the pavement marking technology variable was used as a between-subjects variable because the participant pool varied by material test session.

The second variable, overhead lighting, varied based on whether the overhead lighting was on or off. When the overhead lighting was on; 400-watt high pressure sodium type II-M-C luminaires were spaced at 40 m at a height of 15 m. A full description of the luminaires is included in Appendix A This layout provided a high luminance level and generally uniform illumination on the road surface.

The third factor, glare, was provided by a vehicle which was placed at the end or the start of the marking in the lane opposing the experiment vehicle (see Figure 1). A Sport Utility Vehicle (SUV) was used with halogen headlamps aimed according to Society of Automotive Engineers (SAE) recommendations.

Table 2. Pavement Marking Technologies Used in the Testing

Marking	Technology	Supplier/Trade Name	Image
A	Standard Latex Paint with Standard Glass Beads	The paint and beads conform with VDOT Road & Bridge Specification 2002 Section 246	
B	Standard Latex Paint with Large Glass Beads	Visibeads	
C	Profiled Thermoplastic	Drop on Line by Brite Line Technologies	
D	Wet Retroreflective Tape	3M 750	

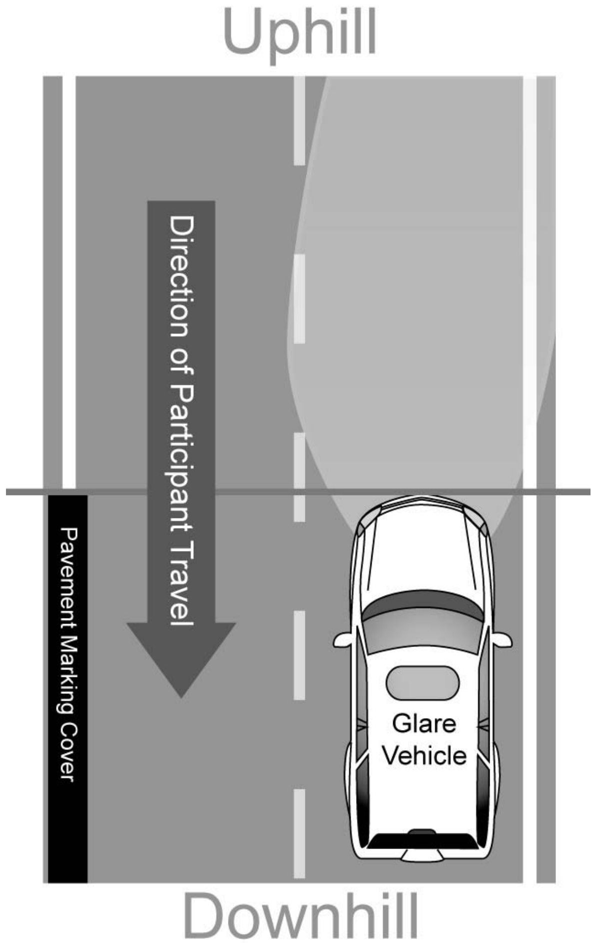


Figure 1. Glare Vehicle Position with Respect to the Experimental Station

For the pavement variable, the markings were installed on two different pavement types, asphalt and concrete. Each section was 0.25 mi long and longitudinally sloped at 6 percent. As described, only the white edge markings were changed for this investigation.

The final factor, vehicle type, provided two different viewing angles of the roadway. This was provided using a sedan and a tractor trailer as the experimental vehicles. As the driver licensing requirements of the sedan and the truck are different, the vehicle type was deemed a between-subjects factor.

Dependent Variables

Several dependent variables were measured in this investigation. These variables include: the detection distance of the pavement markings during continuous rain and during recovery, the photometric characterization of the markings, and the evaluation of the pavement markings in dry conditions.

Wet Dynamic Pavement Marking Performance

The detection distance of the beginning or the end of a pavement marking was used as the dependent variable throughout the dynamic driving experiment. During the testing session, participants were asked to detect the beginning or the end of the pavement markings on the same side of the road as they were traveling. The detection distance was measured as the distance from start or the end of the marking to where the driver first detected the marking transition. This distance was measured using a system inside the vehicle that recorded the detection point and the point where the vehicle passed the start or the end of the marking.

The start and end points of the markings were created by covering portions of the edge line with pavement marking covers. The specific locations of the start and end points were moved during each test run on the Smart Road by adding and removing covers at each test station. An example of a covered pavement marking is shown in below.

Figure 2. End of Pavement Marking on Asphalt

Recovery Performance

After the dynamic testing was completed, the rain system was turned off and the markings were allowed to start drying (i.e., recovering). Immediately following the rain shut-off, the participant would again perform the start- and end-point identification task and the detection distance was measured. The time from the shut-off of the rain to the detection of each marking was also recorded.

Photometric Characterization

The final assessment of the pavement marking was the photometric performance or the measurement of the lighting characteristics of the marking. The luminance of the marking and the vertical illuminance from the vehicle headlamps along the marking was measured at the mean detection distance for each experimental station. The luminance values were measured with a Charged Coupled Device (CCD) photometer which allows for the measurement of the marking itself as well as the background. The background measurement of the marking incorporates the pavement surface shown behind the marking itself. From these values, several other calculated variables can be derived. These are shown in Table 3.

Table 3. Calculated Variables from Luminance and Illuminance Measurements

Center Luminance	Measured at the end or beginning of the marking from the mean detection distance with the CCD Photometer
Left, Right Luminance	Measured on the adjacent left and right of the end of the marking with the CCD photometer
Background Luminance	Average of the left and right luminance $Background = \frac{(Left\ Luminance - Right\ Luminance)}{2}$
Contrast	Contrast of Marking and Background $Contrast = \frac{(Marking\ (Center) Luminance - Background)}{Background}$
Calculated Retroreflectivity R_L	Calculated from the luminance and illuminance measurements $R_L = \frac{Marking\ (Center) Luminance}{Illuminance} \bullet 1000$
Luminance Dosage	Calculated as the luminance of the marking * size of the object in Steradians
Retroreflectivity Dosage	Calculated as the retroreflectivity of the marking * size of the object in Steradians

Dry Dynamic Pavement Marking Performance

The evaluation of the pavement markings in the dry conditions was performed in an identical manner as the evaluation in wet conditions, except for the use of the simulated rain on the Smart Road test area. The dependent variables in this evaluation were the same as those in the wet performance evaluation.

Experimental Materials

The materials required for the project consisted of the experimental area, the pavement markings and covers, the experimental vehicles, and the photometric measurement equipment.

Experimental Area

The experiment was performed at the Smart Road facility in Blacksburg, VA, which is a unique, state-of-the-art, full-scale research facility for pavement research and evaluation of vehicle and infrastructure technologies. For this experiment, the 0.5-mile all-weather test area of the Smart Road was used as the primary experimental area. In this area, the roadway is sloped at a consistent 6-percent slope. The roadway consists of two 3.6-meter (12-foot) lanes, one in each direction, with a 3-meter shoulder on each side of the roadway.

The pavement in the test area consisted partially of bituminous asphalt and concrete. Both pavement sections were aged for over 5 years.

Six test stations were selected along the roadway in the experimental area. Of these six stations, three were located in the asphalt area and three were located in the concrete pavement section. The configuration of the stations and the experimental area is shown in Figure 3. During the experiment, the experimental vehicle drove between the Top Turn and Turnaround 3. Stations 1, 2 and 3 were used for the "Downhill" portion of the driving lap, which is from Top Turn to Turnaround 3, and Stations 4, 5, and 6 were for the "Uphill" run back to the Top Turn. The station type also varied in terms of whether it represented a beginning or an end of the pavement marking. Table 4 shows the stations, the travel direction, and the station types.

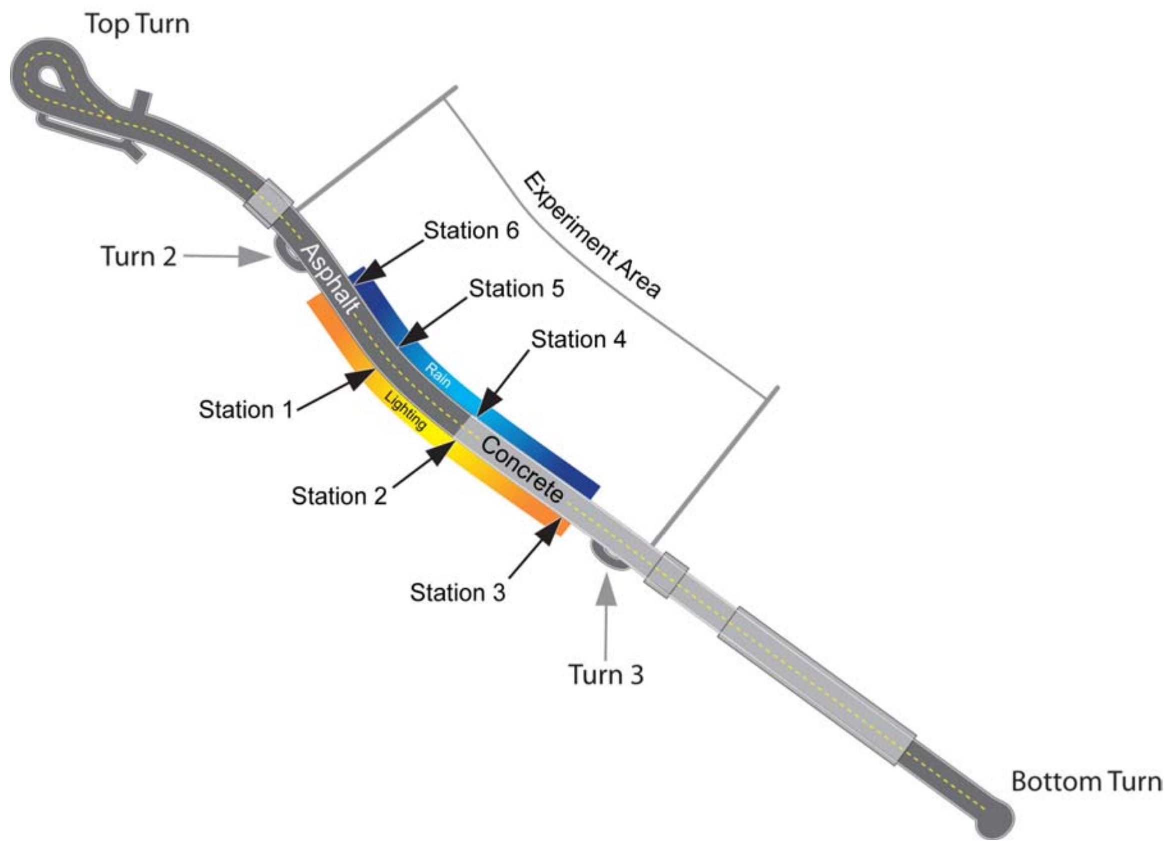


Figure 3. Overview of the Experimental Route with Station Locations, Rain System Configuration, and Lighting Configuration on the Smart Road

Table 4. Station Types and Travel Direction

Station	Travel Direction	Station Type
1	Downhill	End
2	Downhill	Start
3	Downhill	End
4	Uphill	End
5	Uphill	Start
6	Uphill	End

The simulated rain for the experiment was provided using the Smart Road all-weather testing capabilities. The rain is provided by 75 towers located every 30 ft along the Smart Road. The tower heads were positioned over the centerline of the pavement marking area and constant water pressure was distributed to the rain-making towers along the side of the roadway. Each tower was equipped with a control valve to individually tune the tower's water pressure. Because the experimental area is sloped, individual tower control was required in order to provide an even rain distribution across the entire experimental area. The experimental area with the rain system functioning is shown in Figure 4.

Figure 4. Smart Road All-Weather Testing System

The rain system performance was characterized using standard rain measurement gauges. These measurements were made using seven gauges spread in a row across the road starting underneath one rain tower. After the measurement, the gauges were moved 10 ft along the roadway. This was continued three times until the row of gauges was immediately underneath the next rain tower. This process allowed for evaluation of the consistency of the rain across the experimental area. The results of these measurements, shown in Figure 5, reveal a deviation across the road with the highest rainfall on the rain tower side of the road. Stations 4, 5 and 6 were at the edgeline location on this side of the road with Stations 1, 2, and 3 along the edgeline on the opposite side of the road. The mean rainfall for the entire driving space (edgeline to edgeline) was 0.8 in/h with a mean rainfall of 0.23 in/h on the opposite side (Stations 1, 2 and 3) and 1.08 in/h on the tower side (Stations 4, 5, and 6).

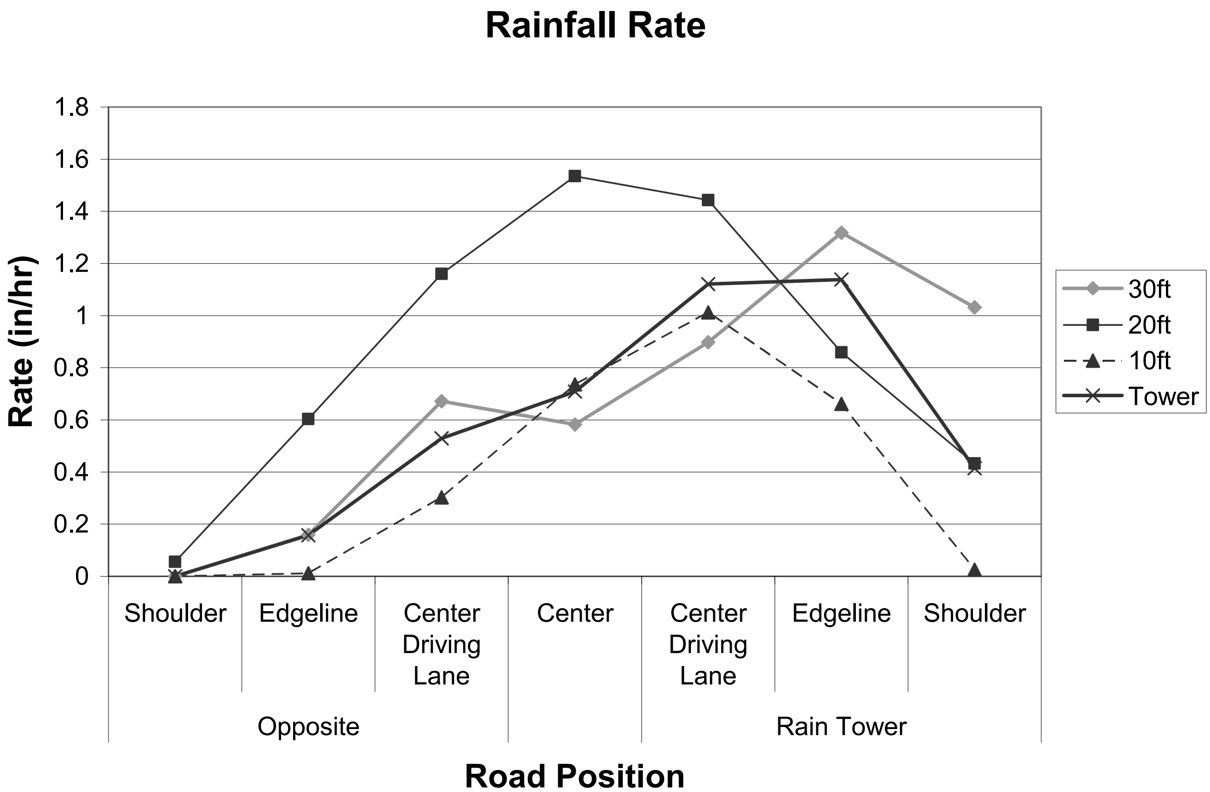


Figure 5. Rainfall Rate Characterization

The rainfall deviation along the length of the roadway appears to be less substantial than across the roadway. Highest levels appear at the 20-foot location which is halfway in-between the measured tower and the adjacent tower. Overlap from one tower to the next is likely the cause of this elevated rate at the midpoint.

Pavement Markings and Covers

Four different types of pavement markings were viewed by the participants during the evaluations. As mentioned, these were installed on the experimental area from one end to the other in a standard edgeline formation. The technologies used are summarized in Table 2.

The covers used to provide the start and end points for the investigation were made of black-asphalt-rolled roofing material purchased from a local home improvement center. The material was purchased in 36-foot rolls and sliced to 9-inch widths. Successive rolls were placed over the markings to provide the beginning and end points. In order to provide adequate breaks in the markings and to provide a clear beginning and end point, a minimum of three successive rolls were placed on the markings at each station.

Experimental Vehicles

The two experimental vehicles used were a sedan and a truck tractor, both with standard halogen headlamps. The sedan was a 2002 Cadillac Deville, and the truck was a 1997 Volvo VN Series class 8 tractor.

The headlamps were aimed using the standard SAE alignment method. For the photometric characterization, it should be noted that using two headlamps for calculation of a single value of retroreflectivity is not typical as each light source results in a different value of retroreflectivity due to the different geometries presented by the headlamp, point on the road, and the driver.

The actual viewing height and the headlamp height for each of the vehicles are summarized in Table 5.

Table 5. Vehicle Headlamp and Viewing Heights

Vehicle	Headlamp Height	Entrance Angle	Viewing Height	Observation Angle
Sedan	27 in	88.7°	45 in	0.87°
Truck	37.5 in	88.2°	88 in	2.44°

Measurement Equipment

Two instruments were used in the experiment: an illuminance meter and a CCD photometer.

For the roadway illuminance measurement, a Minolta T-10 illuminance meter was used with a waterproof remote measurement head and a standard instrument body. A constructed fixture held the detector head in a vertical orientation. The instrument lay flat and centered on the pavement marking and was aimed at the experimental vehicle during the measurement. When measuring in the rain, variation in the measurement required that the staff members performing the measurement manually average the reading over time. The illuminance reading was the vertical illuminance at the marking mid-point. As the calculation of retroreflectivity requires the illuminance normal to the incident angle of the light, the illuminance values should be corrected by multiplying by the cosine of the angular difference between the vertical and the normal of the incident angle. This angle was approximately 1.3 deg for the sedan, and 1.7 deg for the truck. As this would result in a correction factor less than 0.05 percent, and for consistency across all of the conditions, this correction was ignored.

The luminance was measured with a Radiant Imaging CCD photometer with a 50-millimeter lens. The CCD photometer provided a method of capturing the luminance of an entire scene at one time. The object of interest in the scene can then be analyzed. Using the software provided with the system, the average luminance of the object and that of its background were measured as shown in Figure 6. In this image, the white boxed region was recorded as the marking or center luminance and the gray boxed regions were recorded as the left, right, and top background luminance values.

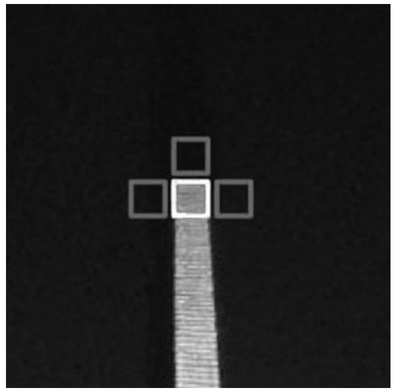


Figure 6. CCD Photometric System Analysis Regions

Participants

Since the pavement markings were tested serially, the duration of the data collection period of this project was from September 2004 to February 2006. Due to this length of time, the same participant group could not be used for all of the test sessions. In all, 54 participants were used, 32 for each test session. Eight subjects participated in only 1 session of the study; 20 subjects participated in 2 sessions; 9 subjects participated in 3 sessions; and 14 subjects participated in all 4 sessions of the study.

Participants were chosen after successful completion of a screening questionnaire (Appendix B). During the initial screening, participants had to verify possession of a valid driver's license, confirm that they were free from medical conditions that would present a risk, and provide appropriate age and gender demographics. Following the initial screening portion of the experimental session, participants were then asked to fill out an informed consent form (Appendix C). The consent form outlined their right to freely withdraw from the experiment at any time without penalty. Furthermore, the form conveyed that they would be remunerated at a rate of $20 per hour for their participation.

When the participants were first greeted for the test session, they were asked to complete driving background questionnaires. The questionnaire asked for details about the number of years that they were licensed, the average number of miles driven per year, the number of miles driven in the past two years, average number of miles driven at night, and their use of corrective lenses. The questionnaire also asked about the concerns when driving at night in bad weather. An example of the questionnaire used is in Appendix D.

The participants were also tested for their visual acuity, contrast sensitivity, color vision, and glare sensitivity.

For each session, to provide the statistical power required from the experimental design, 16 participants were tested in the sedan and 16 in the truck. The age range for the sedan participants was 65 years or older and the group was balanced for gender. Conversely, the truck participants were 40 years or older and were all male. The mean ages for each of the experimental sessions are shown in Table 6.

Table 6. Age Summary for Each Experimental Session

Session	Group	Mean Age	Min Age	Max Age	Standard Deviation
All	**All**	**62.52**	**40**	**80**	**8.19**
	Sedan Male	**68.21**	**65**	**80**	**3.49**
	Sedan Female	**68.02**	**59**	**75**	**3.15**
	Truck Male	**56.93**	**40**	**72**	**7.40**
Paint and Regular Beads	**All**	**62.90**	**47**	**80**	**7.82**
	Sedan Male	68.56	66	80	4.15
	Sedan Female	68.31	66	74	2.35
	Truck Male	57.35	47	71	6.82
Paint and Large Beads	**All**	**62.45**	**47**	**75**	**7.59**
	Sedan Male	67.50	66	72	1.93
	Sedan Female	69.67	66	75	3.20
	Truck Male	56.31	47	71	5.76
Profiled Thermoplastic	**All**	**63.02**	**41**	**72**	**7.59**
	Sedan Male	67.33	65	69	1.33
	Sedan Female	68.25	66	72	2.07
	Truck Male	58.25	41	71	7.21
Wet Retro Tape	**All**	**61.73**	**40**	**79**	**9.57**
	Sedan Male	69.44	65	79	4.98
	Sedan Female	65.85	59	73	3.58
	Truck Male	55.82	40	72	9.41

Overall, the mean number of years that the participants had held a driver's license was 45 (50 for sedan drivers and 40 for truck drivers). The mean number of miles driven in one year was 29,000 (13,500 for sedan drivers and 46,500 for truck drivers). For both the truck and sedan drivers together, the mean number of miles driven in the last two years was 55,000 (24,000 for sedan drivers and 85,500 for truck drivers). According to the questionnaire data, the mean frequency at which participants drive at night was once per week for sedan drivers and three times per week for truck drivers.

Most participants expressed little difficulty when driving at night. When asked about driving at night in bad weather, participants were concerned with: slick roads (15.2 percent), obstacle/animal/pedestrian (16.7 percent), other drivers/vehicles (37.7 percent), lights/glare (18.8 percent), visibility of pavement markings (26.8 percent), and general visibility (17.4 percent). These results are shown in Figure 7.

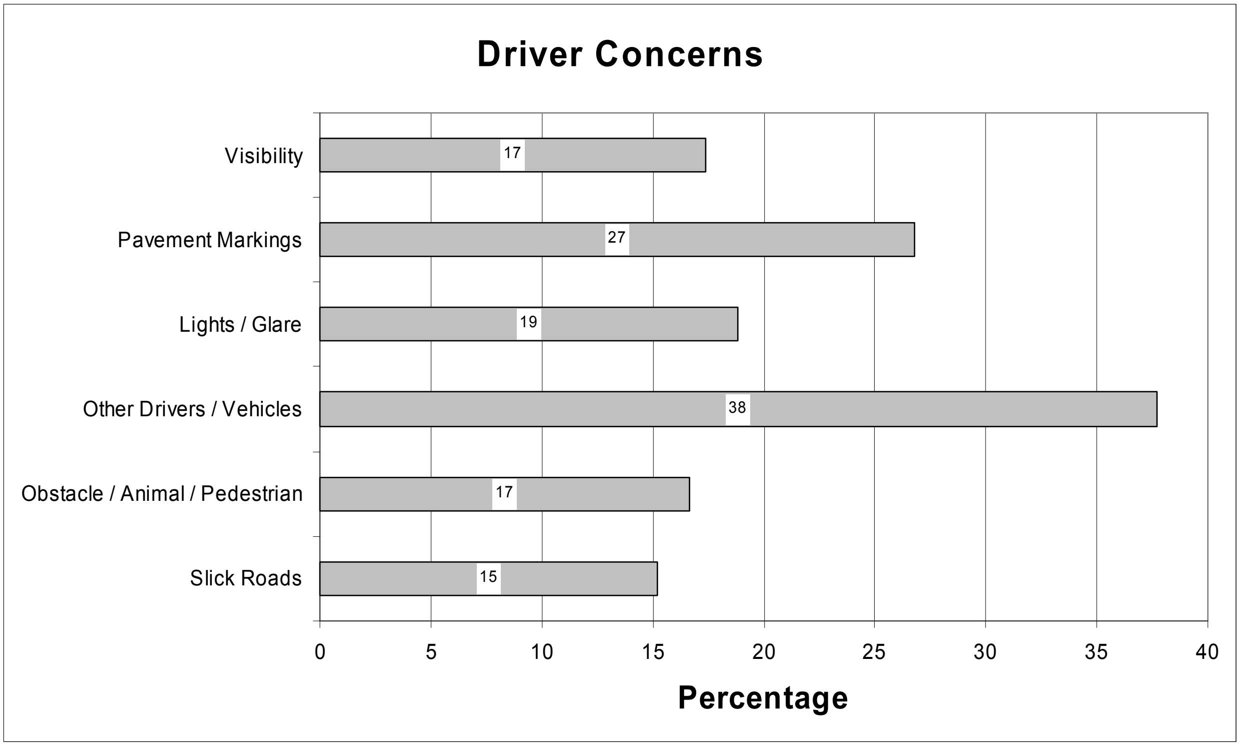


Figure 7. Response of Driver Concerns When Driving at Night

The average acuity score for all participating subjects was 20/22.4 (20/24.6 for sedan drivers and 20/20.1 for truck drivers). No participants demonstrated deficiencies in color or contrast sensitivity.

In terms of glare sensitivity, as expected, the older sedan participants showed a higher sensitivity to glare than the younger truck drivers, however, no significant anomalies were found.

For the dry evaluation of the pavement markings, a subset of six of the participants from each vehicle during the wet evaluation was re-tested in the dry conditions for each material type.

Experimental Method

Each participant was met by research staff at the VTTI building where he or she read the project informed consent, filled out the questionnaire, underwent color and visual acuity testing, and was instructed on the experimental activities. The participant then entered the experimental vehicle and traveled to the test location. An in-vehicle experimenter was in the vehicle with the participant at all times. During the experimental session, two participants were tested simultaneously, one in the sedan and one in the truck. During the experiment, to control for glare issues and for safety reasons, the vehicle paths were controlled such that the vehicles did not pass each other.

When appropriate during the testing procedure, the rain system was activated and the lighting condition was established. During the test session, each participant drove 10 experimental laps on the road at 25 mph. The first lap acted as practice where the participant was familiarized with the test area and procedures. The next four laps were in one lighting condition, followed by four laps with the other lighting condition. The last lap was a recovery lap where the rain system was turned off and the markings were allowed to start drying. The presentation of the lighting and the glare was counterbalanced for each participant.

During each lap, the participant said either "start" or "end" when he or she detected the pavement-marking transition whereupon the experimenter recorded the distance with the vehicle instrumentation system. The point where the vehicle passed the marking transition was also marked with the instrumentation system. The detection distance was calculated as the difference between the first detection point and the point where the vehicle passed the station of interest.

For the recovery lap, the vehicles traveled to a specified pausing location. After the vehicles had paused, the rain was turned off. The time when rain was turned off was recorded in the data file. The lap then proceeded as the previous lap. In the data analysis, the recovery time was able to be derived from the rain turn-off time to the detection time.

During the test session, the glare vehicle was moved to various stations to provide the appropriate condition. In-between laps, the start- and end-line locations were moved by relocating the covers. To minimize experimental order effects, the presentation order of the glare car position and the location of the start/end lines were counterbalanced between participants for all runs of the experimental vehicles.

As mentioned, a secondary task of detecting traffic cones was also performed by the participants. For this task, an orange traffic cone was placed either 120 ft before or 120 ft after either Station 3 or 6. Data on this task were not collected but the task was included to break up the driver glance pattern and ensure that the participant was viewing the entire roadway.

For the dry evaluation of the pavement markings, the same protocol was used except for the recovery testing. For this testing, the participants only drove nine laps on the road.

Data Analysis

The analysis was broken into the same four efforts as the experimentation:

1. Wet dynamic pavement marking performance
2. Recovery
3. Photometric characterization
4. Dry testing results

Wet Dynamic Pavement Marking Performance

The data analysis for the steady-state rain results was undertaken in several steps. The first was a 4 (Pavement Marking Type) by 2 (Lighting) by 2 (Glare) by 2 (Pavement Type) by 2 (Vehicle Type) mixed-factors Analysis of Variance (ANOVA). In this analysis, all five of the main effects and their interactions were included in the analysis. Main effects and interactions were considered to be significant at a confidence interval of 95 percent ($\alpha = 0.05$).

Two further issues were identified as potential influences on the study results. These are the impact of the cone-search task and the impact of the (uphill vs. downhill) orientation of the marking detection task. The data analysis considered each of these effects separately.

For the secondary cone-search task, the cone only appeared at Stations 3 and 6. When the participant vehicle approached these locations, the presence of the cone may have impacted the detection of the end of the marking. As the cone either appeared before the marking, after the marking, or not at all, each of these conditions must be considered. To investigate the potential influence of the cone detection task the results for Station 6 and Station 3 for each of the conditions were further analyzed.

The other potential impact to the results was the uphill and downhill orientation of the detection task. Due to the nature of the Smart Road, the "stations" were located on a 6-percent slope which had the possibility of impacting the draining of simulated rain from the marking. This issue may also be confounded with the varying rain rates encountered across the roadway. To compensate for the possible confound, the analysis utilized stations with similar marking conditions. For example, the concrete condition used Stations 3 and 4 for comparison and Stations 1 and 6 were compared for the asphalt conditions. Due to the potential influence of the cone-detection task and the glare condition, only the no-cone, no-glare conditions were used in these comparisons.

Recovery Performance

The recovery condition was evaluated during the last lap of the test session. To identify a relationship between recovery time and visibility, the simulated rain was turned off and the time (in seconds) that the pavement marking was allowed to dry was recorded. .However, due to the nature of this testing method, the uphill stations (4, 5 and 6) had a longer recovery time than the downhill stations. Furthermore, the uphill stations experienced a higher rain rate compared to the downhill stations. To normalize these impacts, a new factor, the recovery ratio (the ratio of the recovery visibility distance to the mean saturated visibility distance) was calculated for each station. It would be expected that this variable would show a continuous increase in value with time indicating the increase in visibility of the marking.

A 4 (Material) by 2 (Vehicle) by 2 (Lighting) mixed-factors ANOVA was performed on the recovery ratio to identify the significant factors in the recovery. The analysis results are described in greater detail in the appropriate section below.

Photometric Characterization

The analysis of the photometric characterization data was conducted by first analyzing the images taken with the CCD photometer which captured the pavement marking luminance and the background. The next step consisted of the calculation of the photometric variables and the threshold values for each of the variables in terms of the material type and the lighting condition. The purpose of these calculations was the determination of a threshold value. This threshold value is one which is equivalent across all of the material, lighting, and vehicle parameters and would represent a limit which must be reached in order to allow the driver to perceive the marking transition.

The other analysis performed on the photometric data was the correlation of the detection distance to the photometric parameters. This was performed using the Pearson Product Moment Correlation (Pearson's correlation) on the dataset. Based on these correlations, a model of the parameters to the detection distance was developed.

Dry Dynamic Evaluation of Pavement Markings

The analysis of the dry dynamic data was used for the direct comparison to the wet performance data. As the dry experiment consisted of much fewer participants, it does not carry as much statistical power as does the wet experiment. All of the main factors results were compared to those found in the wet conditions.

RESULTS

The results are presented in terms of the four test activities: dynamic performance, recovery performance, photometric characterization, and the dry performance evaluation of the markings. For the results presented in terms of the ANOVA calculations and the significant relationships, a 95-percent significance level is used. For interactions, Student Neumann Kuels (SNK) comparisons were made at the 95-percent confidence interval.

Wet Dynamic Pavement Marking Performance

As mentioned, two analyses were undertaken with the dynamic performance data. The first was a primary analysis, which considered all of the main effects and their interactions. The second was a series of secondary analyses that investigated special conditions in the data.

Primary Analyses

The first analysis is the ANOVA results for the visibility distance performance for the pavement markings in the rain. These results are presented in Table 7. In this table, the significant relationships are denoted with an asterisk in the right hand column signifying that they are significant to a 95-percent confidence limit.

Table 7. Overall ANOVA Results for Material, Vehicle, Lighting, Glare, and Pavement Type in the Rain for All Stations

Source	DF	SS	MS	F value	P value	Sig
Between						
Material	3	7423476.32	2474492	73.58	<.0001	*
Vehicle	1	3021909.15	3021909	89.86	<.0001	*
Material*Vehicle	3	264234.856	88078.3	2.62	0.0541	
Within						
Lighting	1	1035386.03	1035386	143.27	<.0001	*
Material*Lighting	3	769435.108	256478	35.49	<.0001	*
Lighting*Vehicle	1	158412.083	158412	21.92	<.0001	*
Material*Lighting*Vehicle	3	137032.913	45677.6	6.32	0.0005	*
Glare	1	779510.649	779511	228.83	<.0001	*
Material*Glare	3	83983.9816	27994.7	8.22	<.0001	*
Glare*Vehicle	1	36750.7016	36750.7	10.79	0.0013	*
Material*Glare*Vehicle	3	16029.8227	5343.27	1.57	0.2007	
Lighting*Glare	1	227990.436	227990	75.78	<.0001	*
Material*Lighting*Glare	3	79000.4895	26333.5	8.75	<.0001	*
Lighting*Glare*Vehicle	1	3496.135	3496.14	1.16	0.2832	
Material*Lighting*Glare*Vehicle	3	10622.2224	3540.74	1.18	0.3216	
Pavement	1	362588.996	362589	80.86	<.0001	*
Material*Pavement	3	341464.812	113822	25.38	<.0001	*
Vehicle*Pavement	1	95380.9807	95381	21.27	<.0001	*
Material*Vehicle*Pavement	3	20348.0217	6782.67	1.51	0.2149	
Lighting*Pavement	1	179735.123	179735	51.98	<.0001	*
Material*Lighting*Pavement	3	63508.4768	21169.5	6.12	0.0007	*
Lighting*Vehicle*Pavement	1	71781.9468	71781.9	20.76	<.0001	*
Material*Lighting*Vehicle*Pavement	3	7190.7221	2396.91	0.69	0.558	
Glare*Pavement	1	52271.5734	52271.6	19.7	<.0001	*
Material*Glare*Pavement	3	5906.79007	1968.93	0.74	0.5291	
Glare*Vehicle*Pavement	1	1465.6217	1465.62	0.55	0.4588	
Material*Glare*Vehicle*Pavement	3	3242.54639	1080.85	0.41	0.748	
Lighting*Glare*Pavement	1	3226.67121	3226.67	1.11	0.2953	
Material*Lighting*Glare*Pavement	3	4386.02072	1462.01	0.5	0.6825	
Lighting*GlareVehicle*Pavement	1	2687.17982	2687.18	0.92	0.3394	
Material*Lighting*Glare*Vehicle*Pavement	3	10815.8308	3605.28	1.23	0.3003	
Total	63	15273272.2				

* $p < 0.05$ (significant)

As shown in the table above, all of the main effects are significant, there are many significant 2-way interactions and four 3-way interactions are significant. Of the main effects and due to the nature of the research, the marking material type is the most interesting. These results, shown in Figure 8, indicate that the paint with regular glass beads has the shortest detection distance followed by paint with large beads. The thermoplastic material and the tape product have the longest detection distances. The letters at the top of the columns indicate groups that are not statistically different according to the SNK comparisons. For example, the paint with the large beads has a similar performance to the thermoplastic product. An interesting finding is that these results differ from those found in the static experiment. In that experiment, the performance of paint with small and large beads was equivalent, the thermoplastic performed better than the paint with beads, and the tape had the highest detection distances. These results may be the product of the experimental setup. For example, in the static experiment, the pavement was paved without a crown and a 2-percent longitudinal grade whereas in the dynamic experiment the road was paved with a 2-percent crown in the center of the road and a 6-percent longitudinal grade. The greater longitudinal slope and presence of a crown in turn allows for a greater draining of rain water from the pavement marking, which might result in the larger beads performing at a higher level than the smaller beads.

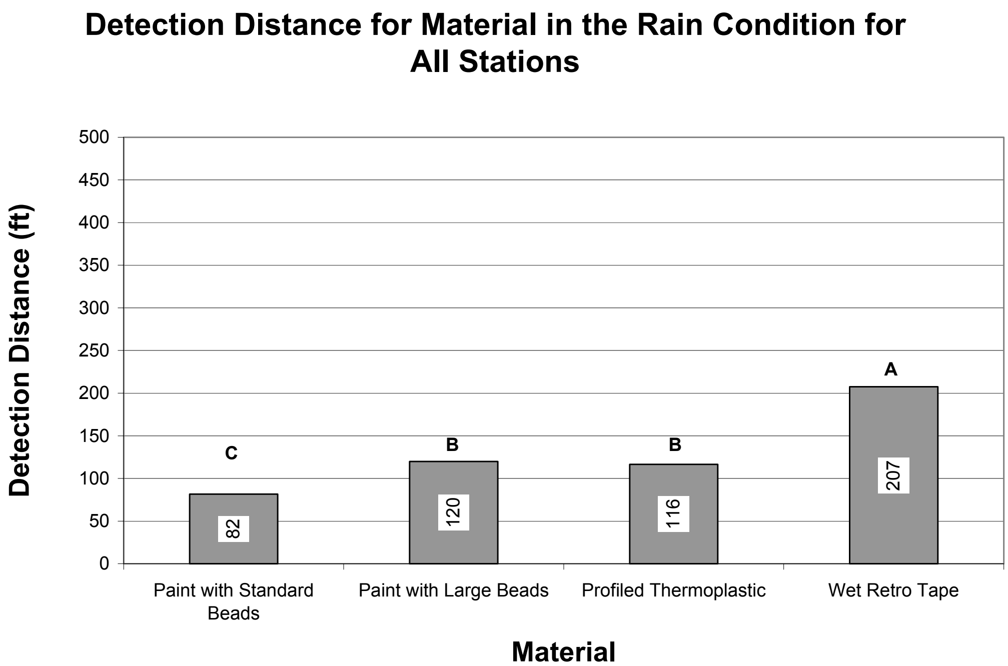


Figure 8. Detection Distance by Material Type in Rain Conditions for all Stations

The next main effect of interest is that of the vehicle type, which is shown in Figure 9. These results show that the participants in the truck detect the markings at a greater distance than those participants in the sedan (161 ft versus 103 ft, respectively). This result is similar to those found in the static experiment. It is believed that the higher perspective from the truck provides a greater visibility distance than the lower observation height of the sedan. Another consideration here might be the additional performance provided by the younger truck drivers as compared to the older sedan drivers. The visual acuity for the truck drivers was slightly higher than the sedan drivers (20/20.1 to 20/24.6) but this value represents less than a single line change on a Snellen Acuity Rating and it is expected that this impact would be minimal.

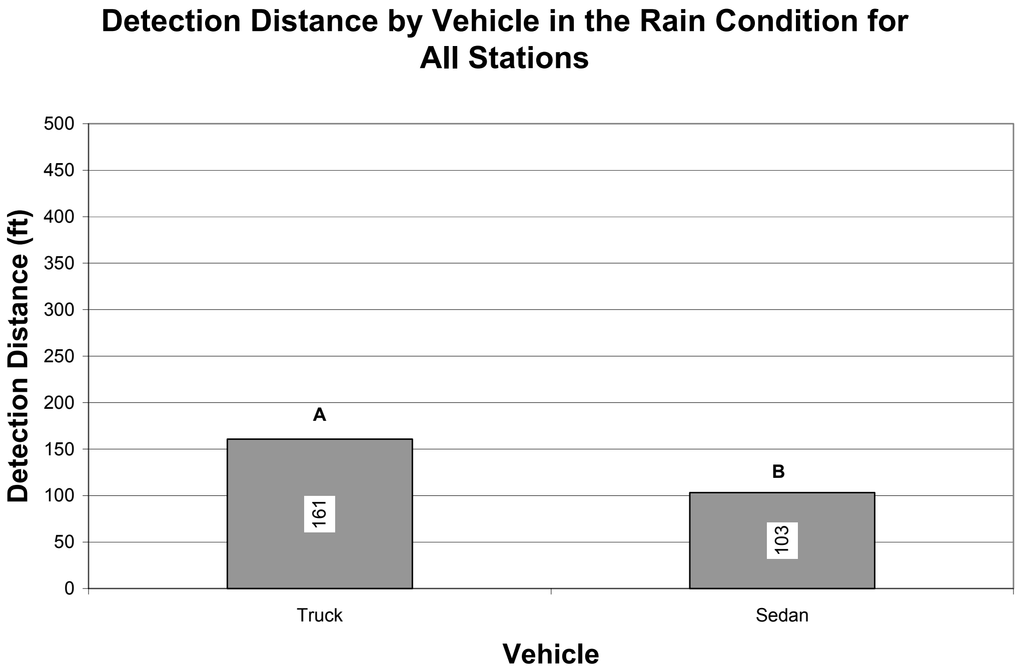


Figure 9. Detection Distance by Vehicle Type in Rain Conditions for all Stations

The next relationship considered is that of the Material Type, Lighting Configuration, and Vehicle Type for which all of the main effects, the 2-way interactions, and the 3-way interaction are significant. This interaction, as seen in Figure 10, indicates that the addition of lighting improves the visibility distance for both vehicle types and for all materials except the tape product. In the case of the tape product, the luminance to the observer was higher than for the other products. The addition of the lighting would brighten the pavement and may actually reduce the contrast of the marking to its background thus minimizing the impact of the lighting.

The main effect of glare as well as the 2-way interactions of Glare and Lighting, Vehicle Type and Material type, and the 3-way interaction of Glare, Material Type, and Lighting are all significant. Figure 11 shows the 2-way interaction of Glare and Vehicle Type. In this interaction, the performance in both vehicles was reduced by the additional glare source. The performance in the truck, however, was reduced by approximately 36 ft where the performance in the sedan was only reduced by 25 ft. This impact was unexpected as the truck, being higher, was thought to be less influenced by glare compared to the sedan where the opposing glare headlamps closer to the line of sight of the participant. The percentage change, however, for both materials, however, shows a similar reduction of approximately 21 to 22 percent for both vehicle types due to the addition of glare.

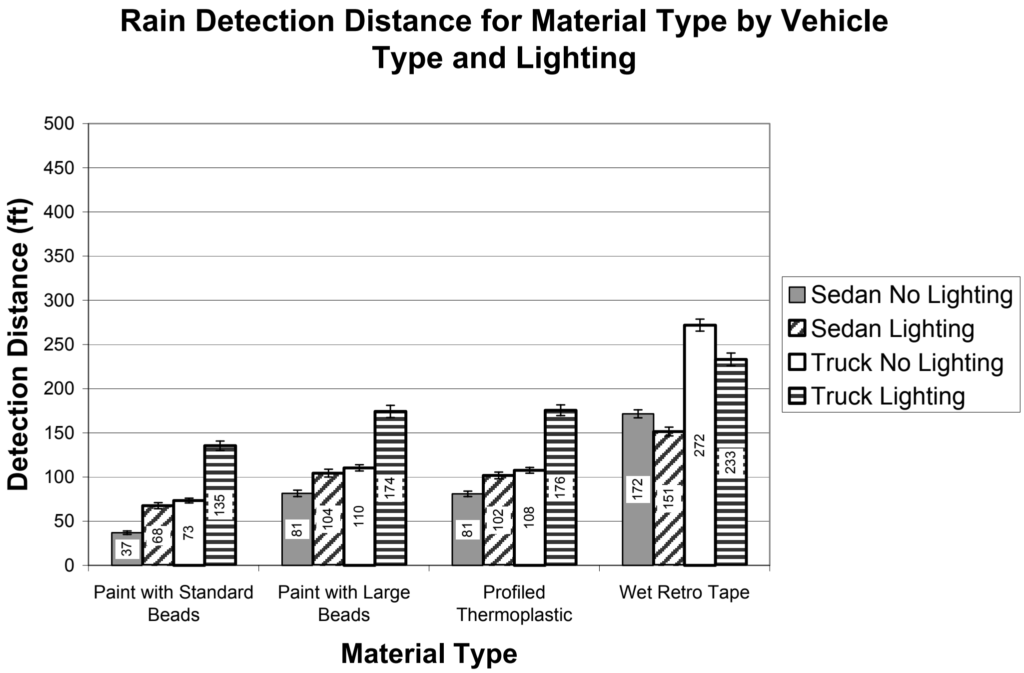


Figure 10. Detection Distance by Material Type, Vehicle Type, and Lighting Condition in Rain Conditions for all Stations

Another relationship of interest is the 3-way interaction of Material Type, Glare, and Lighting. This interaction (see Figure 12) indicates that the addition of the glare reduces the performance for all of the materials; however, the addition of the lighting mitigates the effects of the glare and returns the visibility distance back to the level as it would have been without the glare present. This indicates that the higher adaptation luminance in the eye of the driver provided by the lighting condition counteracts the negative impacts of the glare thus maintaining the detection distance.

The final main effect investigated was Pavement Type. In this case, the pavement main effect was significant along with the 2-way interactions of Pavement Type with all of the other factors and the 3-way interaction with Material Type and Lighting and the 3-way interaction with Vehicle Type and Lighting. The first of these 3-way interactions, Pavement Type, Lighting, and Material Type is shown in Figure 13. In this relationship, an improvement in detection distance for all of the materials, except for the tape product, is seen when placed on concrete as compared to when they are placed on asphalt. For the tape product, the asphalt provides better performance than does the concrete. With the addition of the lighting, improvements are seen for all materials and pavement types except for the tape material where no improvement is seen. This might again imply that the impact of the lighting and the higher luminance concrete is impacting the contrast of the marking with respect to the background it is seen against.

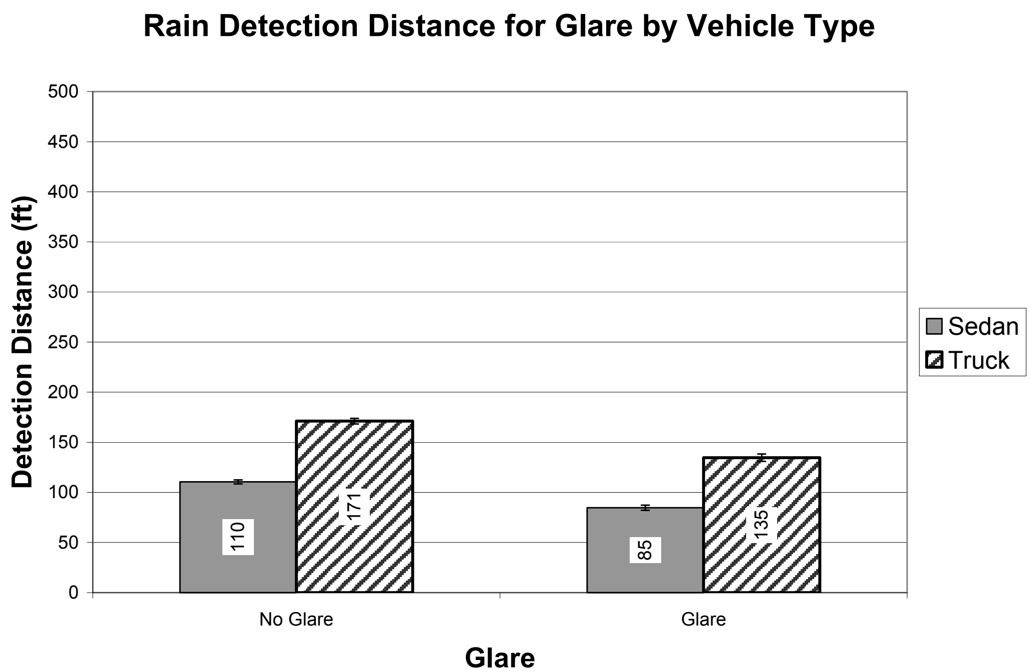


Figure 11. Detection Distance by Glare and Vehicle Type in Rain Conditions for all Stations

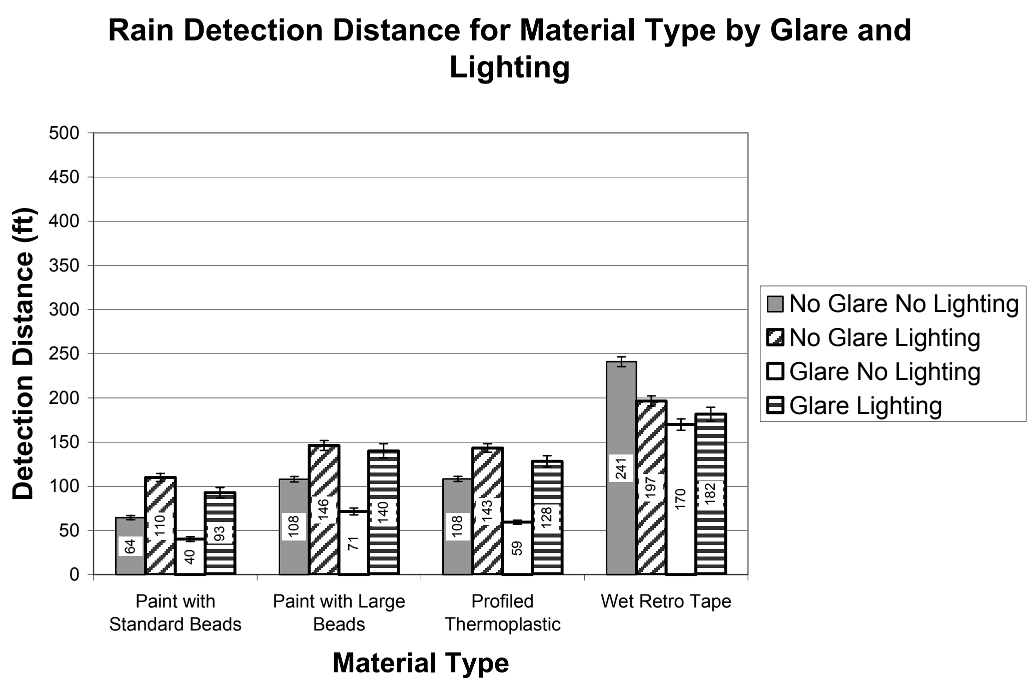


Figure 12. Detection Distance by Glare, Material Type, and Lighting in Rain Conditions for all Stations

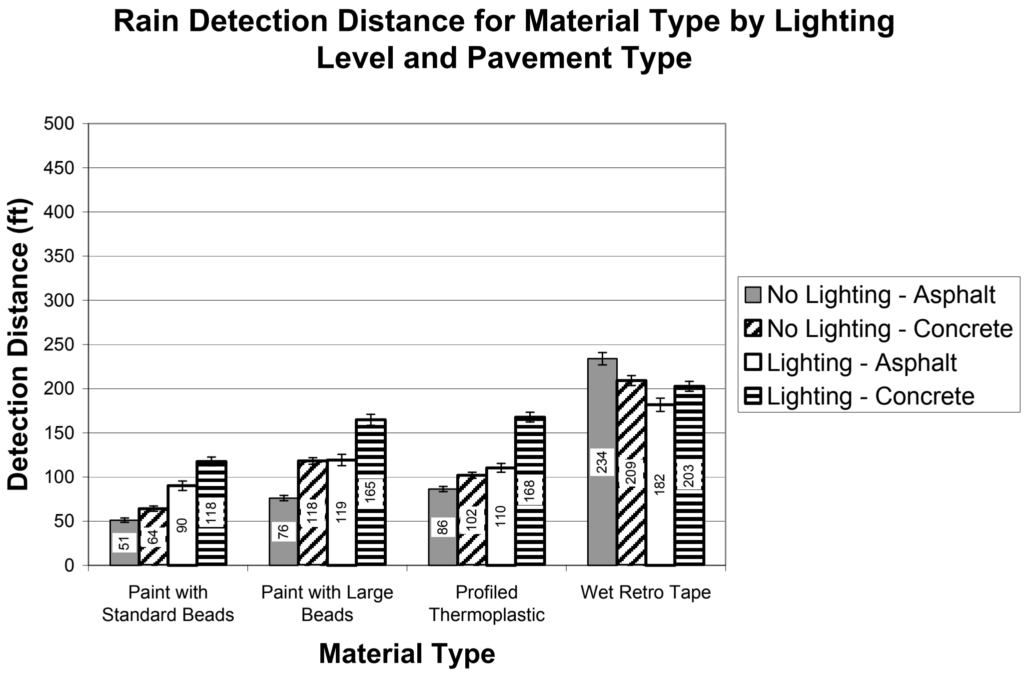


Figure 13. Detection Distance by Pavement Type, Material Type, and Lighting in Rain Conditions for all Stations

The interaction of the Pavement Type, Vehicle Type, and Lighting is shown in Figure 14. In this interaction, the concrete again shows an increase in the detection distance over the asphalt and the truck shows an increase as compared to the sedan. The interaction also shows that the addition of the lighting provides a greater benefit to the truck participants on concrete surfaces than with the sedan participants (59 ft versus 17 ft). This again might be due to the perspective of the truck with respect to the marking and the higher luminance provide by the lighted concrete surface as compared to the darker asphalt surface.

The final interaction is Pavement Type and Glare as shown in Figure 15. In this relationship, both the addition of glare and the asphalt surface reduce the detection distance. The interaction indicates that the glare impacts the concrete to a greater extent than it does the asphalt (40 versus 22 ft), but the concrete with glare level remains higher than the asphalt with glare level (116 versus 106 ft).

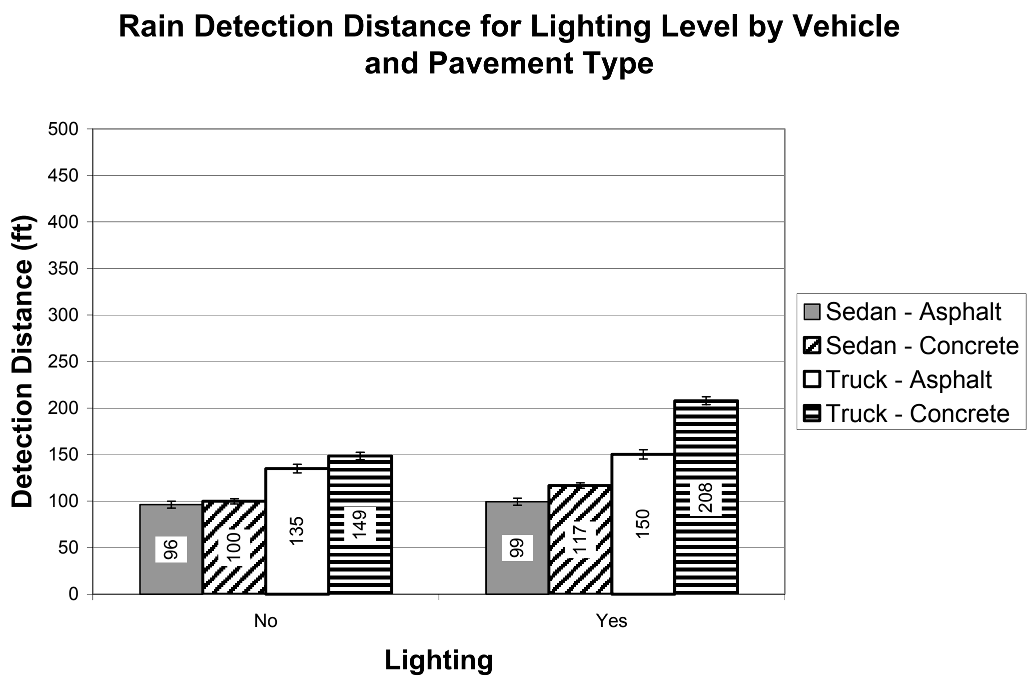


Figure 14. Detection Distance by Pavement Type, Vehicle Type, and Lighting in Rain Conditions for all Stations

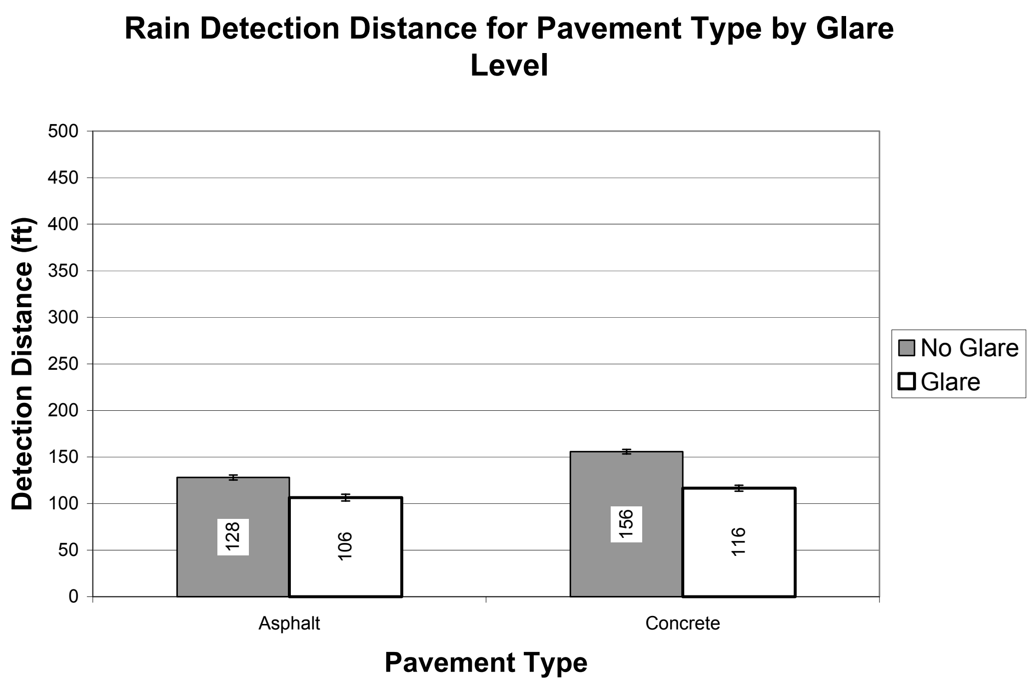


Figure 15. Detection Distance by Glare and Pavement Type in Rain Conditions for all Stations

Secondary Analyses

As mentioned earlier, two secondary analyses were conducted with the data. These consisted of a comparison between stations which had similar characteristics and an investigation of the cone-detection task on the detection distance of the pavement marking.

Similar Station Comparisons

The comparisons of similar stations were performed at two locations. Stations 3 and 4 were both in the concrete pavement section and both represented the detection of an "End" point in the pavement marking. Stations 1 and 6 were in asphalt section and represented an "End" point. It should be noted that Stations 1 and 3 were on the downhill portion of the lap and were on the opposite side of the road from the rain towers thus having a lower rain rate than Stations 4 and 6.

A 1-way ANOVA for the Station 3 and 4 comparison is shown in Table 8. As can be seen from the results, the difference between the stations is significant. This relationship is plotted in Figure 16, where Station 4 had a shorter detection distance than Station 3. The differences found between these stations are likely due to the lower rain rate on Station 3 as compared to Station 4.

Table 8. One-Way ANOVA for Station –Concrete Stations 3 and 4 Only

Source	DF	SS	MS	F value	P value	Sig
Within						
Station	1	703516.775	703517	160.98	<.0001	*
Total	1	703516.8				

* $p < 0.05$ (significant)

The results for the similar comparisons for Station 1 and 6 are shown in Table 9. These results are plotted in Figure 17. Like the previous comparison, the impact of the lower rain rate on the downhill portion of the lap (Station 1) allowed for a longer detection distance than did the higher rain rate on the tower side of the roadway (Station 6).

Table 9. One-Way ANOVA for Station – Asphalt Stations 1 and 6 Only

Source	DF	SS	MS	F value	P value	Sig
Within						
Station	1	367964.925	367965	104.15	<.0001	*
Total	1	367964.9				

* $p < 0.05$ (significant)

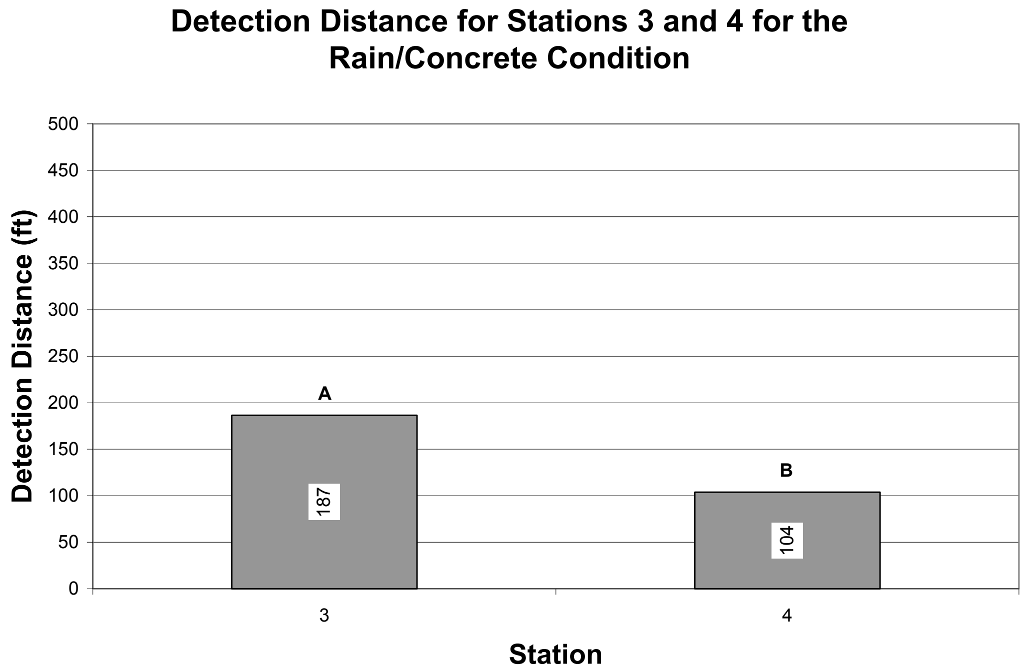


Figure 16. Detection Distance by Station in Rain Conditions for Station 3 and 4Only

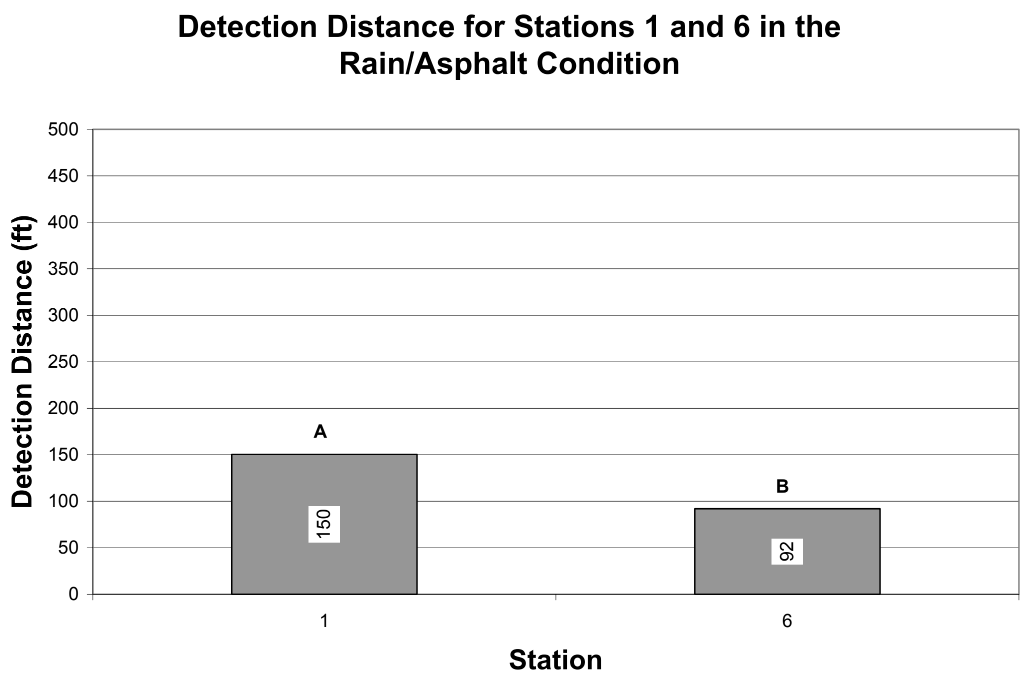


Figure 17. Detection Distance by Station in Rain Conditions for Station 1 and 6 only

These results led to another secondary analysis where the material type, direction of travel (uphill versus downhill), and station type (start of pavement marking versus stop of pavement marking) were considered. The analysis was performed using a 4x2x2 ANOVA, shown in Table 10. In this analysis, all of the main effects and interactions are significant. Since the 3-way interaction is significant, it is likely that the significance of the other factors is shown in this interaction. As seen in Figure 18, the uphill stations, where the rain rate was higher than the downhill, also had lower detection distances. This is consistent for all of the materials except for the tape product where the performance was not affected by the rain rate. The station type also does not seem to make a difference in the results except in the case of the tape product. This again indicates that the tape performance does not follow the same performance trend of the other materials.

Table 10. ANOVA results for Material Type, Travel Direction, and Station Type

Source	DF	SS	MS	F value	P value	Sig
Between						
Material	3	11690676.6	3896892.2	48.35	<.0001	*
Within						
Uphill	1	3020026.31	3020026.3	291	<.0001	*
Material*Uphill	3	1847664.16	615888.05	59.35	<.0001	*
Activity	1	266529.348	266529.35	45.29	<.0001	*
Material*Activity	3	836616.941	278872.31	47.38	<.0001	*
Material*Uphill*Activity	3	1320098.47	440032.82	69.81	<.0001	*
Total	14	18981611.9				

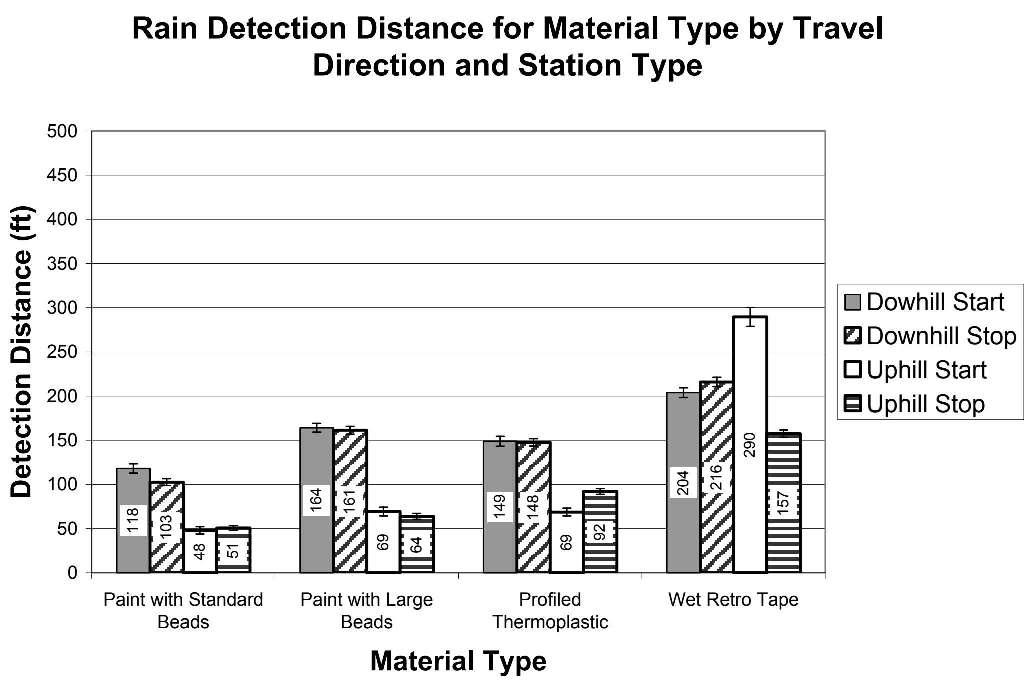


Figure 18. Detection Distance by Material Type, Travel Direction, and Station Type

Impact of Secondary Detection Task

A secondary detection task was used to force the participant to use a wider scanning pattern in order to simulate a more normal driving behavior. This task was performed at Stations 3 and 6 and consisted of placing a cone 120 ft in front of or behind the pavement marking transition point as seen in Figure 19. In this case the cone position (–) indicated it was placed before the marking transition and a (+) indicated it was placed after the marking transition. To investigate the impact of this, a 3x2 ANOVA was used. The results, shown in Table 11, indicate that only the interaction of the station and the cone appeared to be significant. This interaction is shown in Figure 20 where the difference between Stations 3 and 6 is obvious and expected in that Station 6 was on the tower side of the road and Station 3 was on the opposite side of the road from the rain towers and therefore had a lower rain rate. The interaction does show that there was a slight change due to the cone for Station 3. A post hoc SNK analysis as seen in Figure 21shows that the minus position (before the station) had an impact on the detection distance. As this cone position is before the station, it may have given the participant a cue to the station location. The difference, however, is 11 ft and is likely not a significant impact in the analysis.

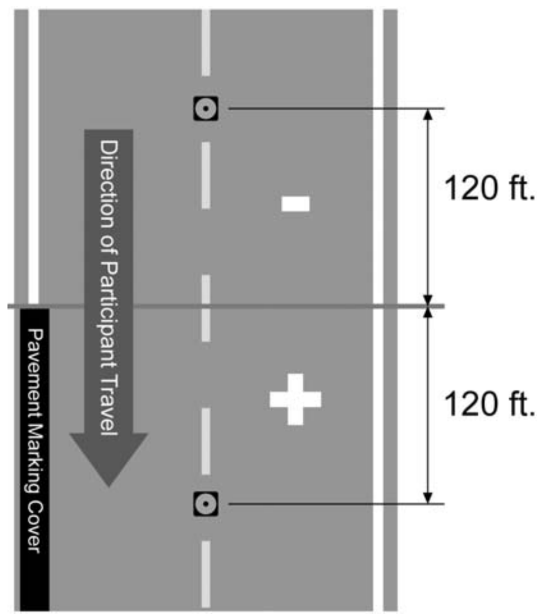


Figure 19. Layout for Secondary Detection Task

Table 11. ANOVA Results for Station and Cone Placement for the Secondary Detection Task - Stations 3 and 6 Only

Source	DF	SS	MS	F value	P value	Sig
Cone	2	8188.3229	4094.1615	1.11	0.3327	
Station	1	1987437.1	1987437.1	260.44	<.0001	*
Cone*Station	2	19550.691	9775.3456	2.83	0.0615	
Total	5	2015176.1				

* $p < 0.05$ (significant)

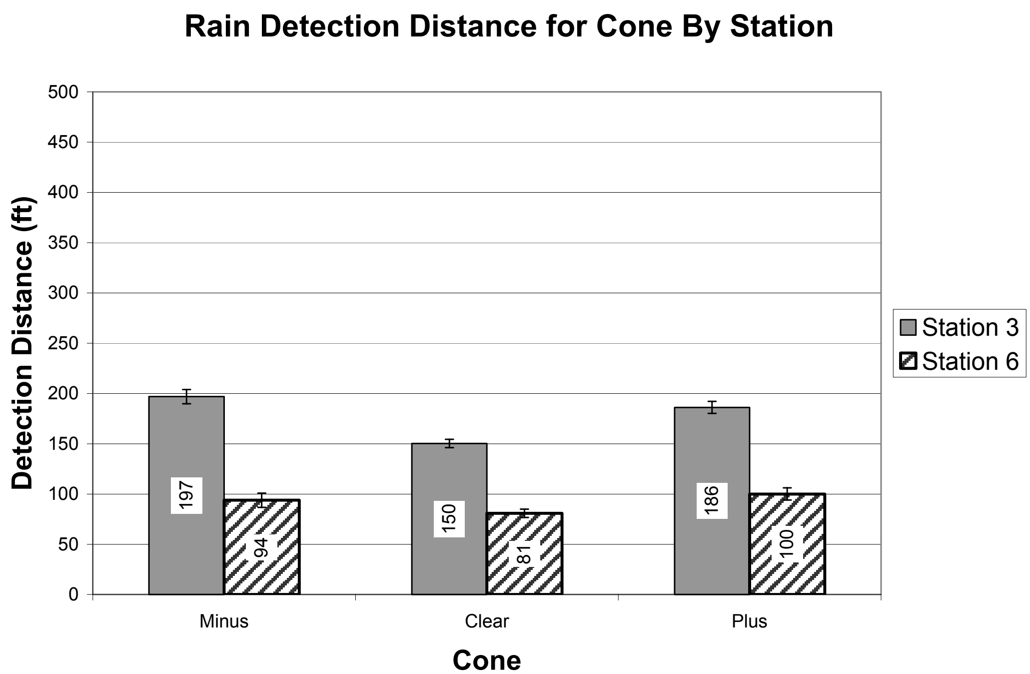


Figure 20. Detection Distance by Secondary Detection Task for Stations 3 and 6

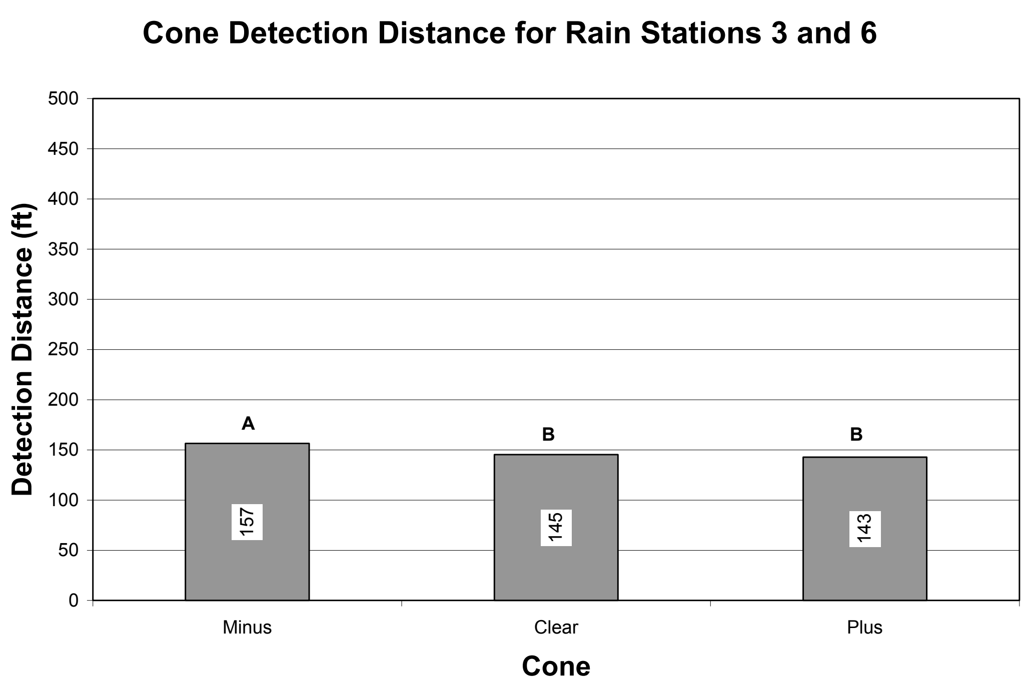


Figure 21. Detection Distance by Secondary Detection Task

Summary

The analysis of the dynamic performance shows very consistent results across all of the variables. Of the materials tested, the wet retroreflective tape product has the highest performance as compared to the other materials. The tape material also does not seem to be impacted as much by the other factors of lighting, vehicle type, pavement type, and glare. The secondary analyses also show that the tape material is not impacted by the rain rate. The detection distance (i.e., visibility) of the other materials does appear to be influenced by all of the tested factors. It is important to note that all of the materials were more easily seen on concrete than on asphalt. In addition, the materials were more easily seen from the truck than from the sedan. Also, glare negatively impacts the visibility of the markings; however this can be mitigated to some degree with the addition of lighting.

Recovery Performance

The recovery testing, which represents the performance of the materials in a drying condition, was completed at the end of the experimental session after the rain system was turned off. The initial recovery data considered was detection distance only. It was expected that the detection distance would increase as the time for recovery increases. The recovery distance results for this experiment are shown in Figure 22. For this figure, the data were broken into 50-second time periods for analysis and as a result the number of measurements in each time period varies. The data gathered used both the sedan and truck detection distances and both lighting conditions. As shown in Figure 22, there is an initial increase in the visibility distance, which is a result of the rain being shut off. When the rain is not being applied, there are no rain drops that the participant must look through and therefore there is an immediate increase in the visibility distance. There is however, no consistent increase in the visibility distance for any of the materials. The distance for the paint and thermoplastic conditions actually decreases rather than increases. It is unclear why this occurs.

The recovery data were analyzed in terms of the recovery ratio, which is the ratio of the recovery visibility distance to the mean visibility distance found during the saturated experiment. These results are presented in Figure 23, where the recovery time is binned into 50-second time periods. These data show that for the paint product there was an initial rise in detection distance performance. The data also show that with the exception of the large bead product, there is no increase in the recovery ratio over time. In the static recovery experiment, the recovery data indicated that the recovery to full visibility was very fast (shorter than the 50-second bins shown here) for the tape and thermoplastic materials and was slower for the paint with standard beads and paint with large beads. This trend is not as clear in this investigation. However, the data do indicate that as the material begins to dry, the large beads may show an increase in the visibility distance earlier than the paint product with standard sized beads.

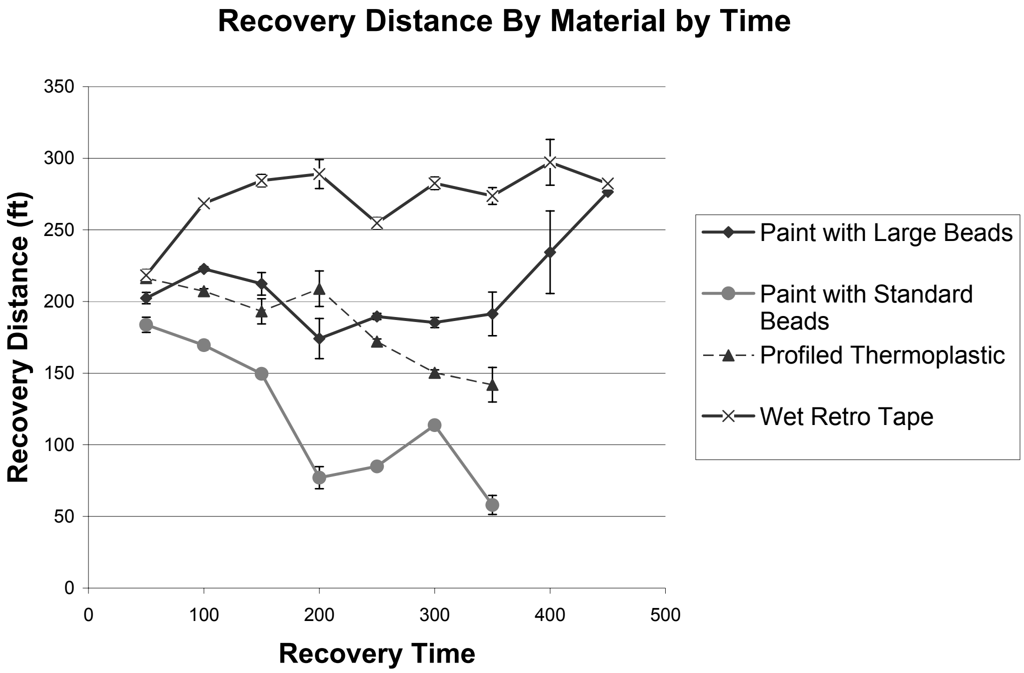


Figure 22. Recovery Detection Distance by Material and Recovery Time including All Vehicle Types and Lighting Conditions

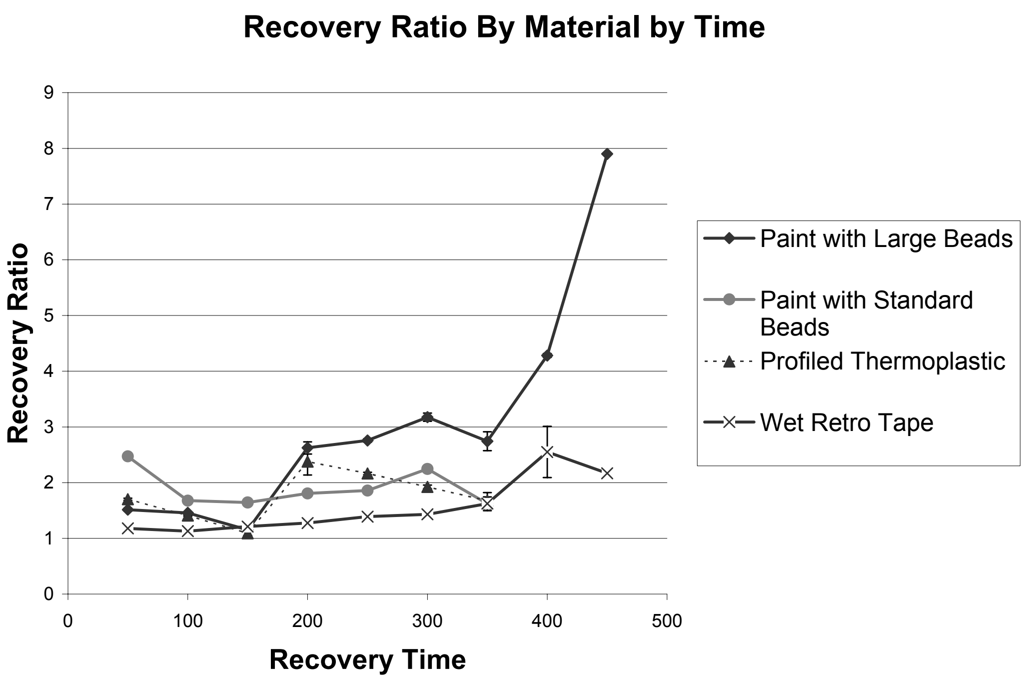


Figure 23. Recovery Ratio by Material and Recovery Time Including All Vehicle Types and Lighting Conditions

Further analysis shows that when considering the factors of Material Type, Lighting, and Vehicle, the impact of these factors is not consistent. These results are shown in Figure 24.

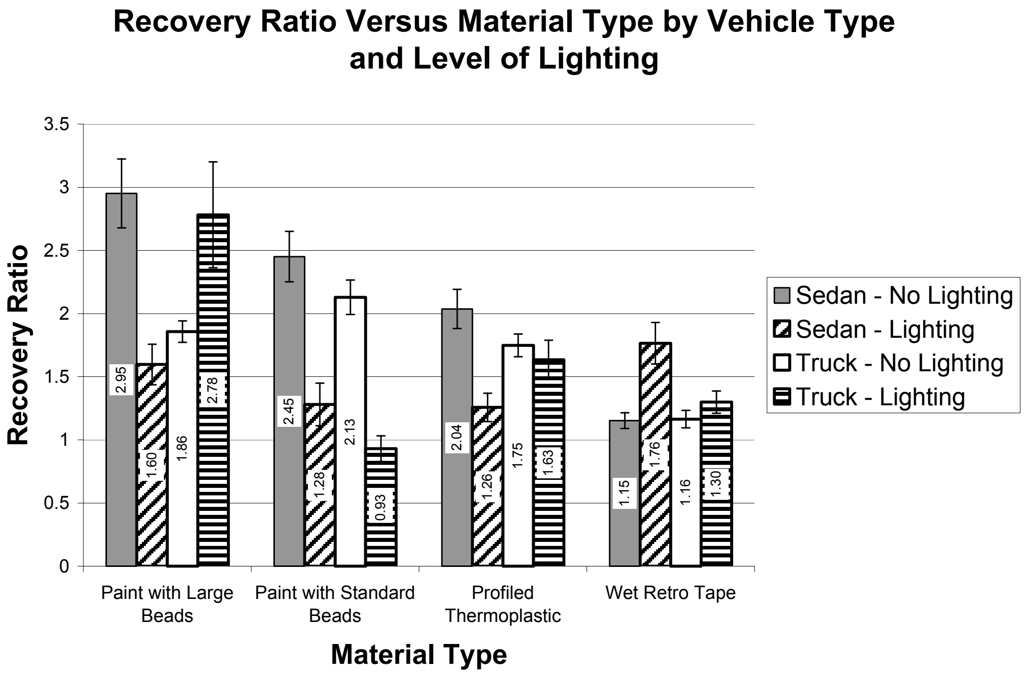


Figure 24. Mean Recovery Ratio Results by Material, Vehicle Type, and Lighting Condition

Here it can be seen that in the no-lighting conditions, the sedan and the truck both show performance increases with the bead materials and the paint products over the thermoplastic and the tape. The unpredictable condition, however, is the addition of the lighting factor which may increase or decrease the detection distance during recovery. For the sedan, lighting decreases performance in all cases except for the tape. For the truck, the results are inconsistent. These results cannot be explained but may be related to the changes in the photometric conditions as the materials recover.

In general, the large bead product shows a benefit during the recovery period after rain compared to the other tested materials. During recovery, the high performance of the tape product does not show an increase, but this material continues to have the longest detection distance during all of the testing.

Photometric Characterization

During the photometric characterization, the illuminance on the marking, the marking luminance, and the background luminance were measured at the mean detection distance. These values represent the threshold values that allow the pavement marking transition to become visible to the participant. Five photometric measures were considered in this analysis: the marking luminance, the contrast, the retroreflectivity, the dosage based on luminance, and the dosage based on the retroreflectivity. The results for each of these parameters in terms of material type and lighting condition are each considered individually. It is noteworthy that an adequate threshold value would be one which is consistent across all materials. This would indicate that the marking would be visible at the distance where this value was achieved regardless of the material used.

The results for the threshold luminance are shown in Figure 25. Here, as would be expected, the luminance in the lighting condition is much higher than in the unlit condition. The luminance of the markings across the material type does show a difference, particularly between the paint and the other material types.

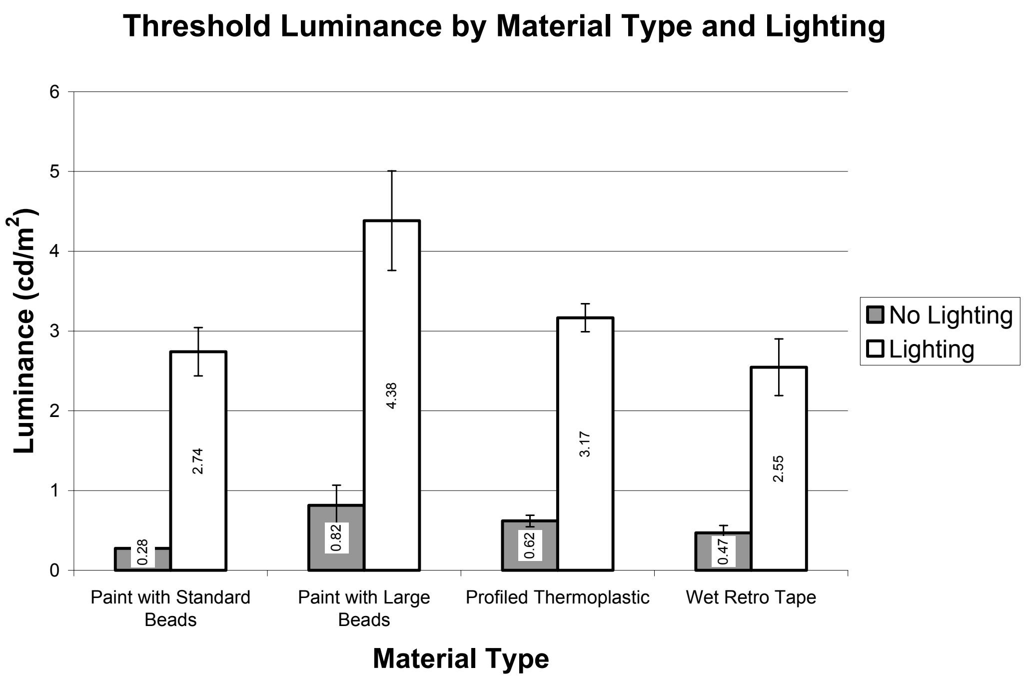


Figure 25. Threshold Luminance Results by Material Type and Lighting Condition

The results for contrast are shown in Figure 26. Here, the contrast increases in the unlit condition from the paint to the large bead material followed by the thermoplastic and the tape material. The high contrast of the tape material may explain the results for the detection distance associated with the tape product. The high contrast of the tape material would allow it to be visible in the glare condition. The other aspect is the reduction in the contrast for all of the products when the lighting is turned on. Here the additional lighting increases the background (pavement) luminance, thus providing a reduced contrast as compared to the no-lighting condition.

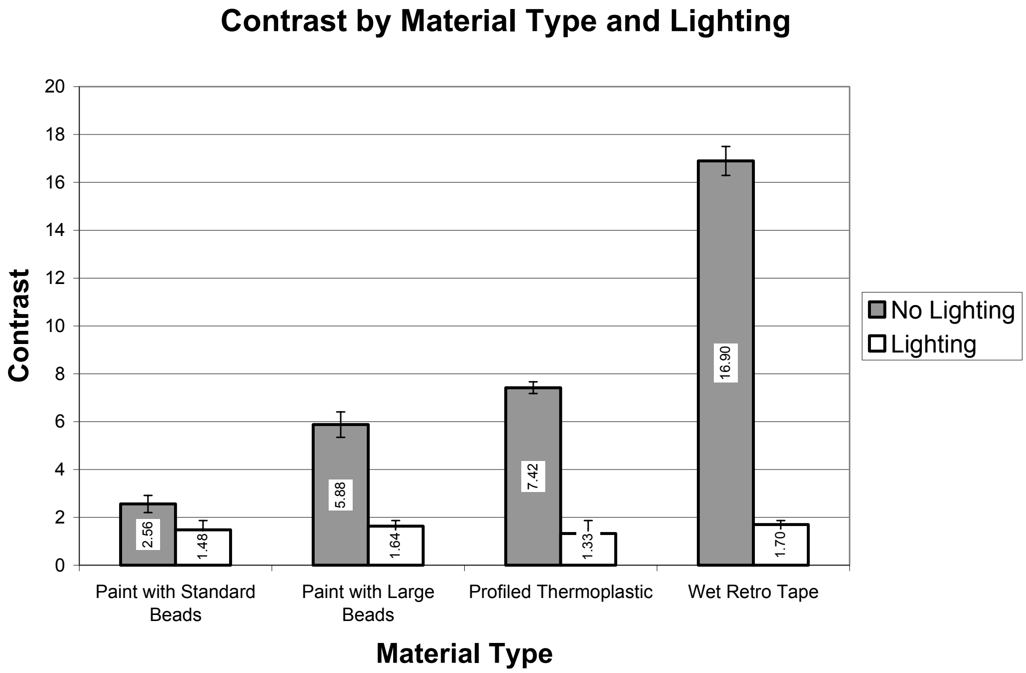


Figure 26. Threshold Contrast Results by Material Type and Lighting Condition

The next parameter considered is the retroreflectivity of the markings. As shown in Figure 27., the retroreflectivity of the materials increases from the paint through the tape material. These values follow the detection distances closely. There is no significant difference between the beads and the thermoplastic materials with the paint and tape each being at different performance levels. With the addition of lighting, the measurement results of the retroreflectivity change. As retroreflectivity is a physical characteristic of the material and will not change with the addition of lighting, this indicates that the additional lighting influences the measurement of the luminance and illuminance and thus a true retroreflectivity value cannot be ascertained. Retroreflectivity is not a suitable threshold value. The distance at which the marking is viewed must be considered. As these data do not include detection distance and are the mean of the measured values, a scaling for the retroreflectivity must be considered.

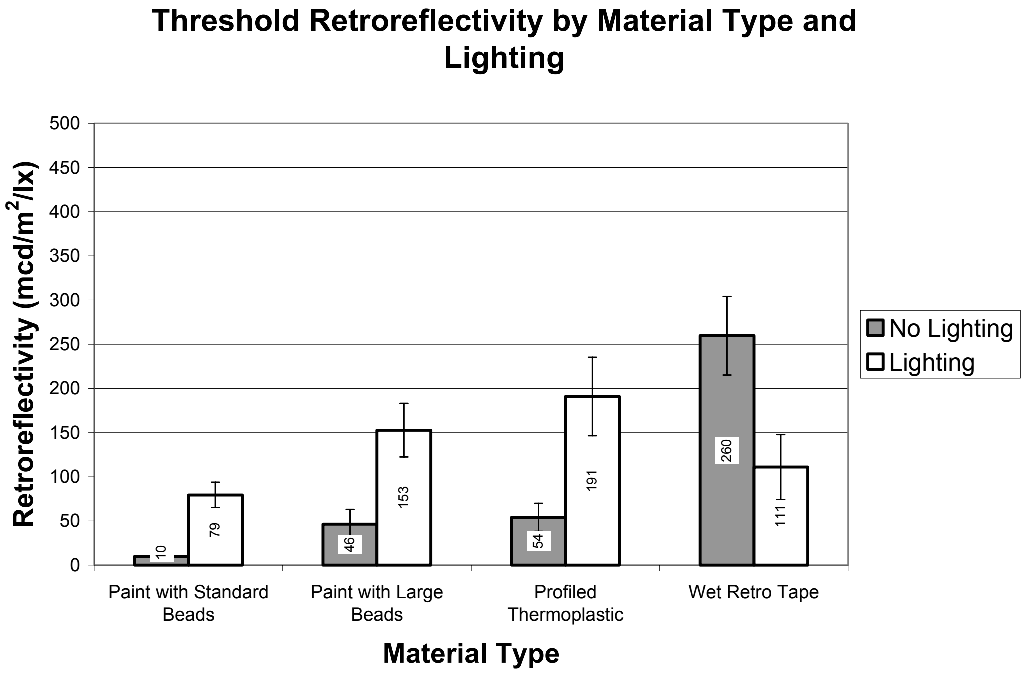


Figure 27. Threshold Retroreflectivity Results by Material Type and Lighting Condition

The dosage factor was developed in the static study [1] to account for the retroreflectivity and the viewing distance by calculating the product of the visual size of the marking in solid angle (measured in steradians [Solid angle = visual area of the object/observation distance]) and the luminance or the retroreflectivity. The static experiment demonstrated the suitability of the retroreflectivity dosage as a threshold criterion. The dosage calculated from the luminance is shown in Figure 28 with the dosage calculated from the retroreflectivity shown in Figure 29. For these calculations, the object size used was the size of a standard 4-inch by 10-foot skip marking. For the luminance dosage, a consistent value in the no-lighting condition is not apparent. In fact, these values follow the inverse of the detection distance relationships. The lighting parameter continues to impact the dosage in an unexpected way. The retroreflectivity dosage in the no-lighting condition does, however, show a consistent value as a threshold for the visibility of the markings. There is no significant difference between all of the measurements except for the tape product, which has a slightly lower threshold value. Based on the apparent suitability of the retroreflectivity dosage, a mean threshold value of 0.0125 sr cd/m^2 (steradians by candela per meter squared) may be used as the threshold of visibility for the pavement markings. This value is higher than that found for the static experiment, which was 0.002533 sr mCd/m^2 lx. The results may be due to the flow of the rain from the markings during the experiment because of the roadway slope or it may indicate that the dynamic nature of the experiment requires a higher threshold level than the static conditions of the first experiment.

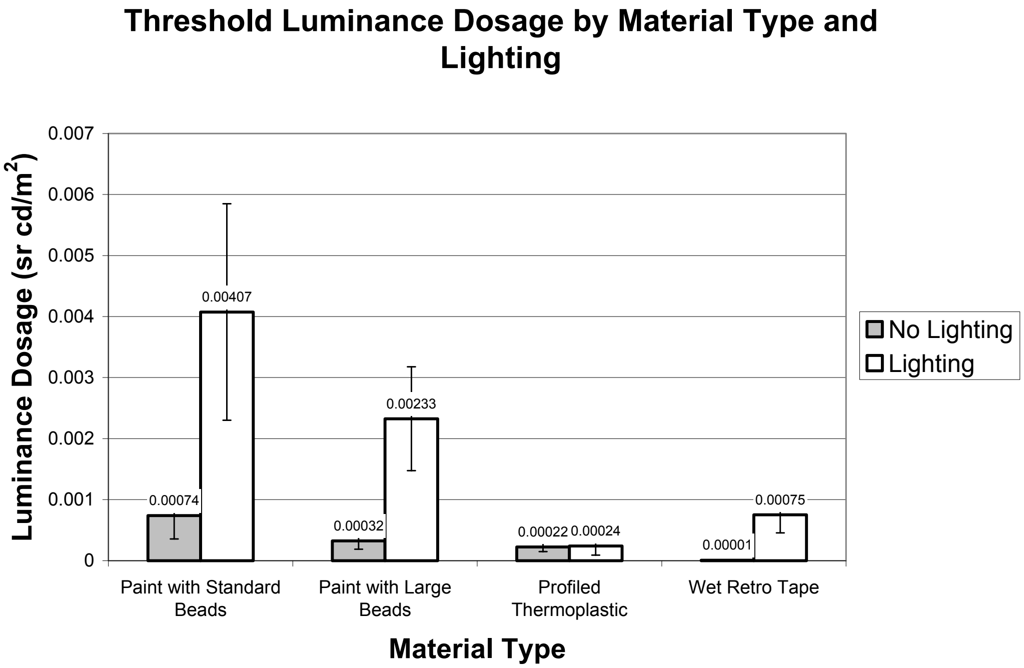


Figure 28. Threshold Luminance Dosage Results by Material Type and Lighting Condition

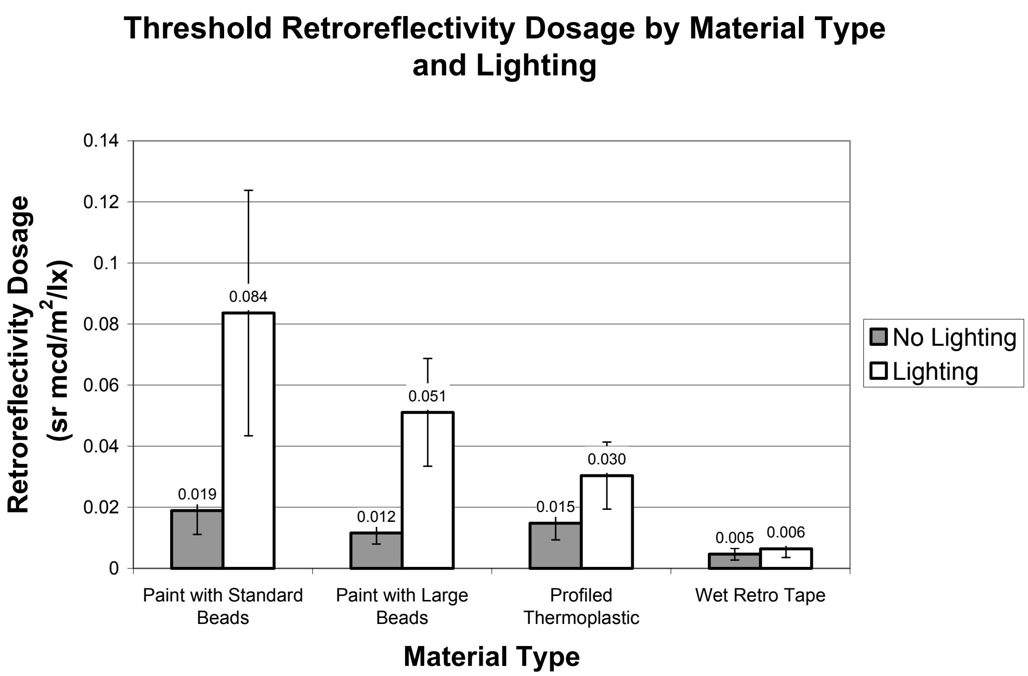


Figure 29. Threshold Retroreflectivity Dosage Results by Material Type and Lighting Condition

One of the issues with the dosage calculations is that vehicle type plays a role in the determination of the threshold. Figure 30 indicates that the sedan has a higher retroreflectivity dosage threshold value than the truck. This again is likely due to the different perspective of the roadway that the truck offers compared to the sedan. The results for the threshold retroreflectivity dosage are similar to those from the static experiments.

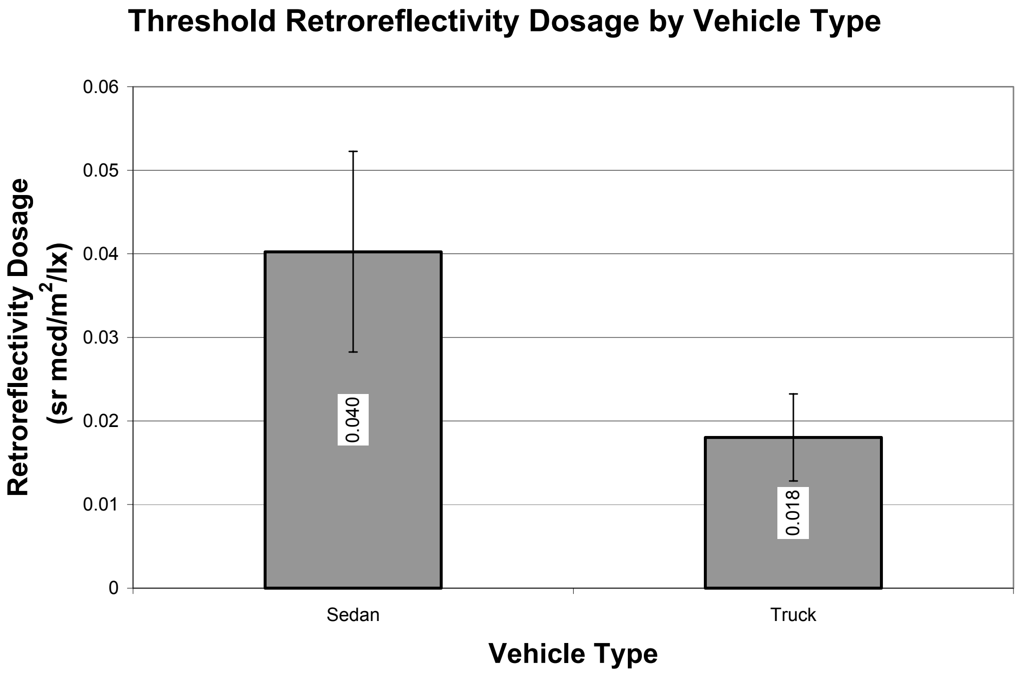


Figure 30. Threshold Retroreflectivity Dosage Results by Vehicle Type

A further analysis of the relationship of the photometric values to the detection distance was undertaken to further investigate the concept of a threshold photometric value for the pavement markings. A Pearson correlation analysis was performed in an effort to build a relationship of the measured and calculated parameters to the detection distance. This analysis was performed for all of the photometric parameters as well as the logarithm (Base 10) of these parameters. In this analysis, both vehicles were included, but only the lighting-off condition was considered. The results of this analysis are shown in Table 12.

Table 12. Pearson R Correlation Matrix for Detection Distance and Photometric Results

Retroreflectivity	0.711
Luminance	-0.022
Contrast	0.626
Luminance Dosage	-0.421
Retroreflectivity Dosage	-0.467
Log(Luminance)	-0.024
Log(Retroreflectivity)	0.644
log(Contrast)	0.496
log(Luminance Dosage)	-0.641
log(Retroreflectivity Dosage)	-0.863

It can be seen that the two variables with the highest correlation to the detection distance are the retroreflectivity and the logarithm of the retroreflectivity. An inspection of a graphic display of the data (Figure 31) shows that the log-linear relationship for the data would be most suitable for modeling. This model can be developed as:

$$Detection\ Distance = a * \log(Retroreflectivity) + b$$

This model was calculated for the truck and the sedan individually as well as an overall model combining both of the datasets. Table 13 shows the results of this modeling as well as the R^2 correlation results. The modeling was performed using a robust regression model with a lowest mean square method, which detected possible outliers in the data (LOESS regression modeling). The model results and the data are shown in Figure 31.

Table 13. Required Retroreflectivity Modeling Results for the Overall Data, Truck and Sedan

	a	B	R^2
Overall	79.33	-10.8	0.1965
Sedan	57.33	-10.2	0.6483
Truck	116.46	-16.55	0.7307

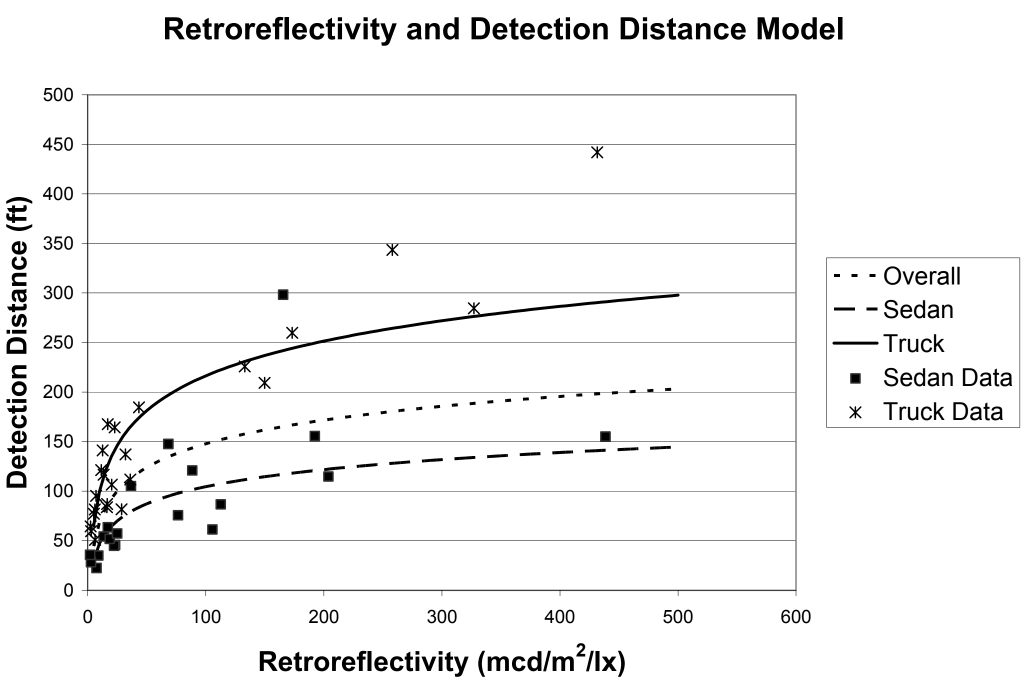


Figure 31. Modeled Threshold Retroreflectivity and Detection Distance

One of the interesting results for this log-linear relationship is that a minimal payback in terms of detection distance is achieved with higher levels of retroreflectivity. From this relationship, it appears that minimal additional benefit to the driver can be accomplished after a level of 200 cd/m2/lx is reached.

In summary, the photometric analysis shows that there is a relationship of the retroreflectivity to the detection distance which can be modeled. The other interesting aspect of the photometry is the idea of the threshold limit for detection of the pavement marking. Both of these two aspects of the results may lead to the development of the requirements for the visibility of pavement markings in wet night conditions.

Dry Dynamic Pavement Marking Performance

The Dry Dynamic Pavement Marking performance was undertaken to investigate what the performance of the pavement markings technologies were in dry conditions for comparison with the wet pavement marking results. As mentioned previously these results were analyzed for comparison purposes only, as there were only 6 participants in this experiment as compared to the 32 for the wet testing condition. Each of the main factors was considered in the comparisons, but for brevity these factors were combined in the presentation of the data.

The first comparison for the detection distance by material and glare condition is shown in Figure 32. Here, the obvious impact is the reduction in the visibility distance due to the wet condition. In the dry condition, the beads, paint, and thermoplastic materials show equivalent performance, while in the wet condition the paint had a lower performance than the other materials. In general, the glare impacted the markings in the same manner for both the dry and the wet condition; the detection distance was substantially reduced. In all conditions, the tape product performed the best.

Figure 33 shows the comparison for the vehicle type and the lighting condition. Here, the impact of the rain is seen in reduction of the detection distance for all of the vehicles and the lighting conditions. The truck continues to have an advantage over the sedan in the dry condition. The lighting improves the visibility for all of the conditions, but it also seems to provide an additional improvement for the truck in the dry condition as opposed to the sedan.

The final comparison is that of the impact of the pavement type and rain condition on the detection distance. Here, the asphalt surface showed a higher detection distance in the dry condition than that of the concrete, whereas in the wet condition the concrete outperformed the asphalt. This is an interesting result and is likely due to the color changes in the pavement materials in the wet condition. When the concrete is wet, the material becomes dark brown. It is likely that in this scenario the contrast of the pavement marking increases against this dark background, thus making it more visible.

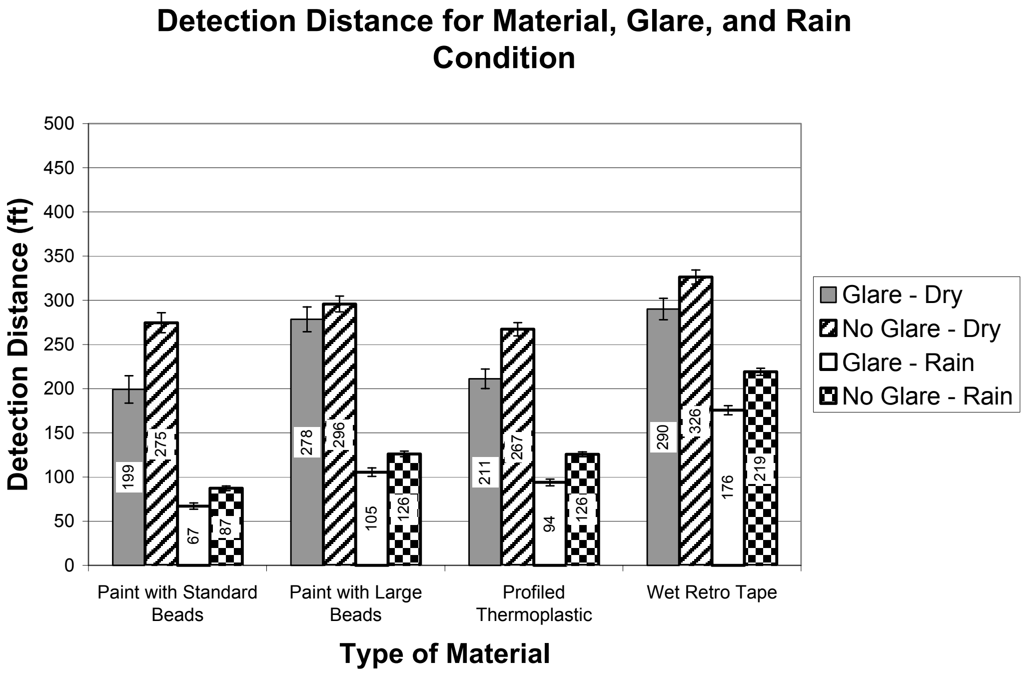


Figure 32. Detection Distance for Material Type, Glare, and Rain Condition

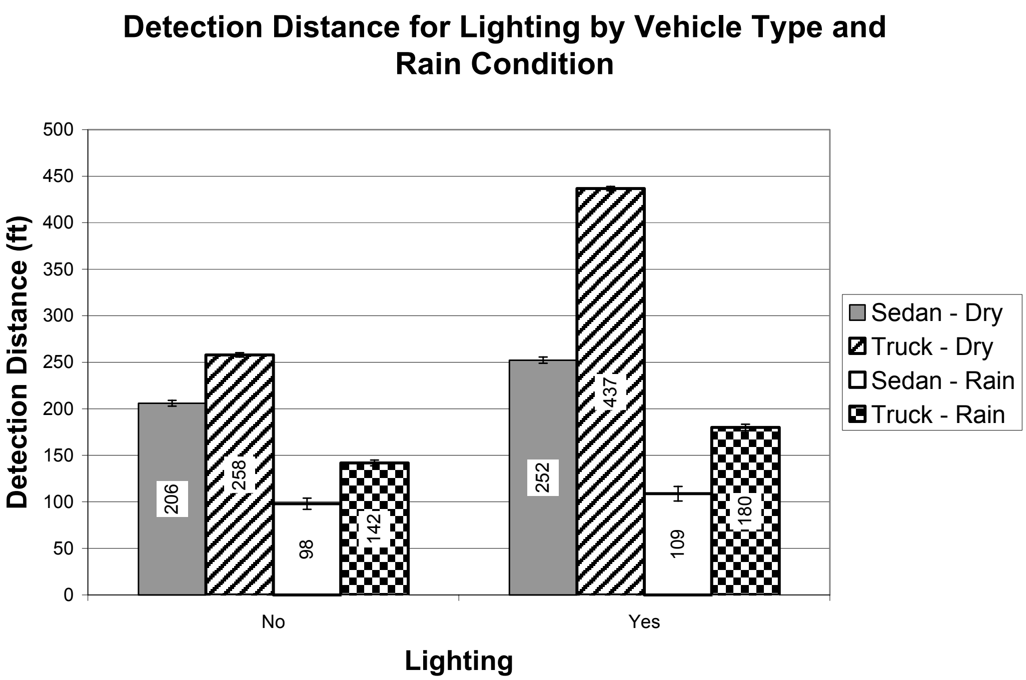


Figure 33. Detection Distance for Vehicle Type, Lighting Condition, and Glare Condition

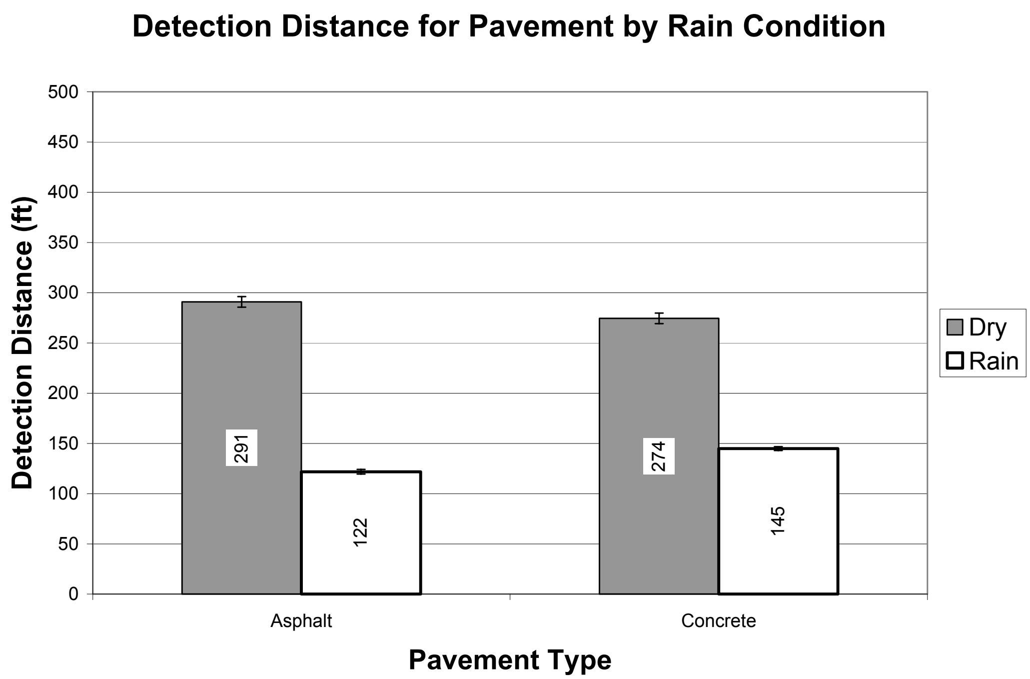


Figure 34. Modeled Threshold Retroreflectivity and Detection Distance

In summary, rain significantly reduced the visibility distance of the pavement markings for all of the conditions. Most of the results were the same as those of the wet conditions except for the pavement type where the asphalt seemed to perform better in the dry condition than in the wet when compared to the concrete surface.

Comparison of the Dynamic and Static Experiment

The visibility distance results of this dynamic experiment are comparable to those in the static experiment, however, the recovery results showed a greater variation in the dynamic experiment and a comparison is not able to be made.

The comparison of the results is shown in Figure 35 where the static experimental results are shown as columns and the dynamic results are shown as lines. In this figure it can be seen that the trends in the static and the dynamic results are very similar except for the paint thermoplastic technology. With this material, the performance in the dynamic experiment dropped to a level similar to that of the paint with large beads. In general, the performance in the sedan was lower for the dynamic experiment than the static, where the truck performance was similar with the exception of the thermoplastic material. This reduction in visibility distance is likely due to the additional workload on the driver in a dynamic situation as compared to the static observations.

One item to note is that the performance of the Raised Retroreflective Pavement Markers (RRPMs) remains superior to the other materials in both experiments. This is a consideration that must be made when specifying the material to be used by VDOT.

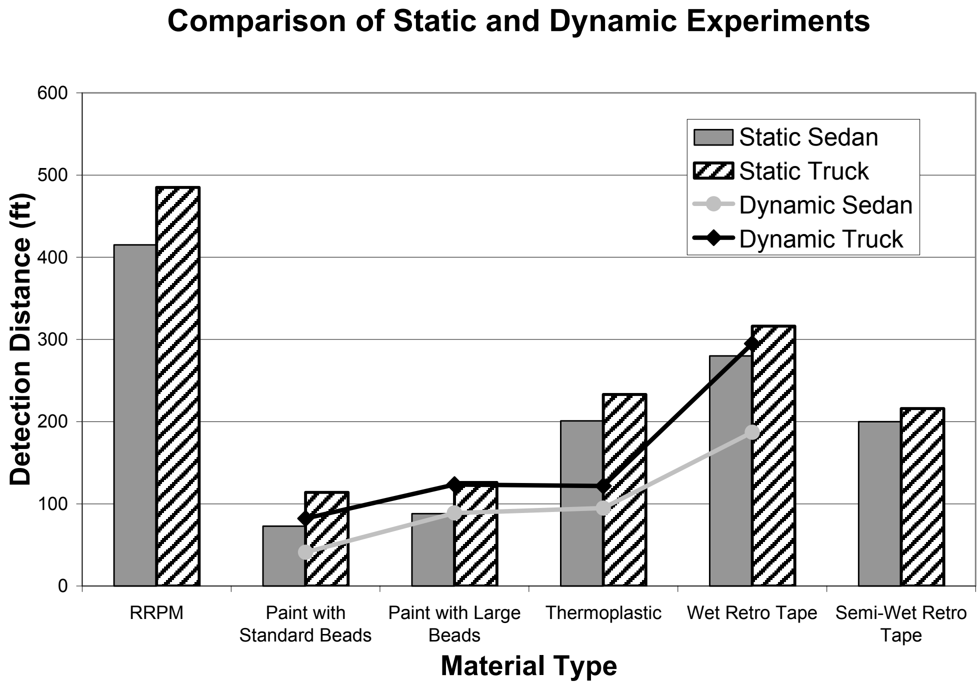


Figure 35. Comparison of Static and Dynamic Experimental Results

A Pearson correlation calculation was performed between these datasets. The results show an overall correlation coefficient of 0.86 with coefficients of 0.87 for the Truck and 0.90 for the Sedan.

Findings Summary

The following points summarize the finding from the experimental results:

- In wet conditions, materials with higher retroreflectivity in the rain have longer detection distances. Standard VDOT paint with standard size beads do not perform as well as other products. Large beads perform better than standard beads and perform equally with profiled thermoplastic products. Tape material designed specifically for wet night conditions performed superiorly to all of the products.
- The use of lighting on the roadway increases the detection distance of the pavement markings.
- The presence of glare from headlamps decreases the detection of pavement markings and the markings require a higher retroreflectivity to compensate for this. However, the effects of glare can also be mitigated by the use of lighting.
- The vehicle type and therefore the observation height also influence the detection of pavement markings. A higher vehicle will allow the markings to be seen from a longer distance.
- The performance of the materials in a recovery condition was not significantly different. Only the paint with the large bead product showed an elevated recovery rate.

- The comparison of the results from the static and the dynamic experiments shows that these two study results are highly correlated.

DISCUSSION

The experimental issue investigated in this project was the level of retroreflectivity required to provide adequate visibility distance in wet night conditions. To further investigate this issue, the performance of the markings in light of the human performance requirements must be discussed. As pavement markings are primarily used for tracking, the required visibility distance is one that will allow the driver to react to an event in the roadway. The Roadway Delineation Practices Handbook [3] specifies 2 to 3 s of visibility for pavement markings based on research performed to establish the required limits of visibility both in adverse conditions and for ease of guiding the vehicle.

Two different methods of establishing the pavement marking performance to achieve this requirement are available from the results of the experiment. The first is the determination of the requirements from the threshold retroreflectivity dosage value and the second is from the retroreflectivity vs. detection distance model.

Using a threshold retroreflectivity dosage value of 0.0125 sr mcd/m^2 lx, the relationship of the retroreflectivity to distance can be calculated based on the object size at various distances. In this calculation, the visual size of a standard 4-inch by 10-foot skip marking was calculated at 2- and 3-second preview times for various speeds. These values were then used with the threshold value to determine the retroreflectivity required for those preview times at various speeds. The results (see Figure 36) show that a value of 500 mcd/m^2/lx value may be required for highway speeds. A limit of 260 is plotted on the figure as this is the mean of the highest retroreflectivity found in the dynamic experiment.

The second method for the calculation of a limit is the retroreflectivity-distance model developed using the logarithm of the retroreflectivity values. Using this model, the speed of the vehicle can be used to calculate the required retroreflectivity of the pavement marking. Figure 37 shows this relationship for the worst case scenario, which is the sedan for both a 2-second viewing time and a 3-second viewing time. Note that logarithmic scales are used for clarity. The same 260 mcd/m^2/lx value is plotted on this figure.

It is noteworthy that the model developed is valid up to the limit of the retroreflectivity measurements made for this project and may not represent performance outside of these limits. No measurements of the pavement marking retroreflectivity were made above the 1000 mcd/m^2/lx.

The required retroreflectivity for vehicle speeds over 45 mph found by either calculation were not achieved by the materials tested in this project. This is a similar result to that found by Schnell et al. [4] where the retroreflectivity of the markings was inadequate for a 3-second visibility for vehicle speeds over 55 mph. It is interesting that both calculation methods provide similar results in the region where this experiment was performed.

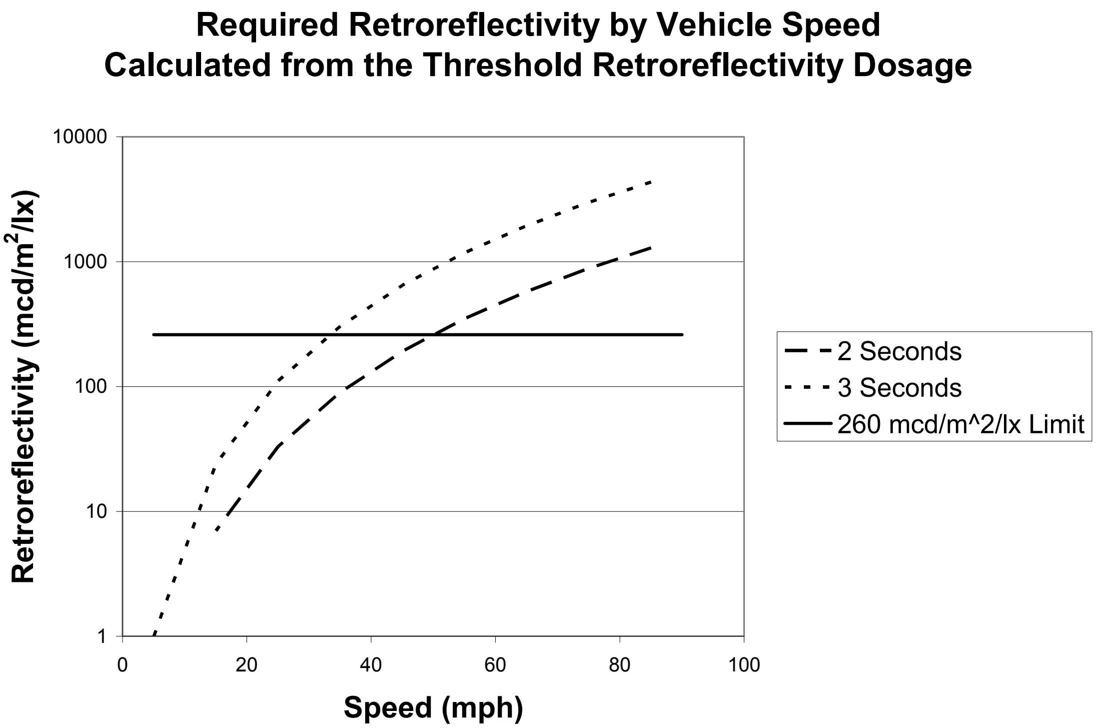


Figure 36. Required Threshold Retroreflectivity by Vehicle Speed for the Dosage Calculation

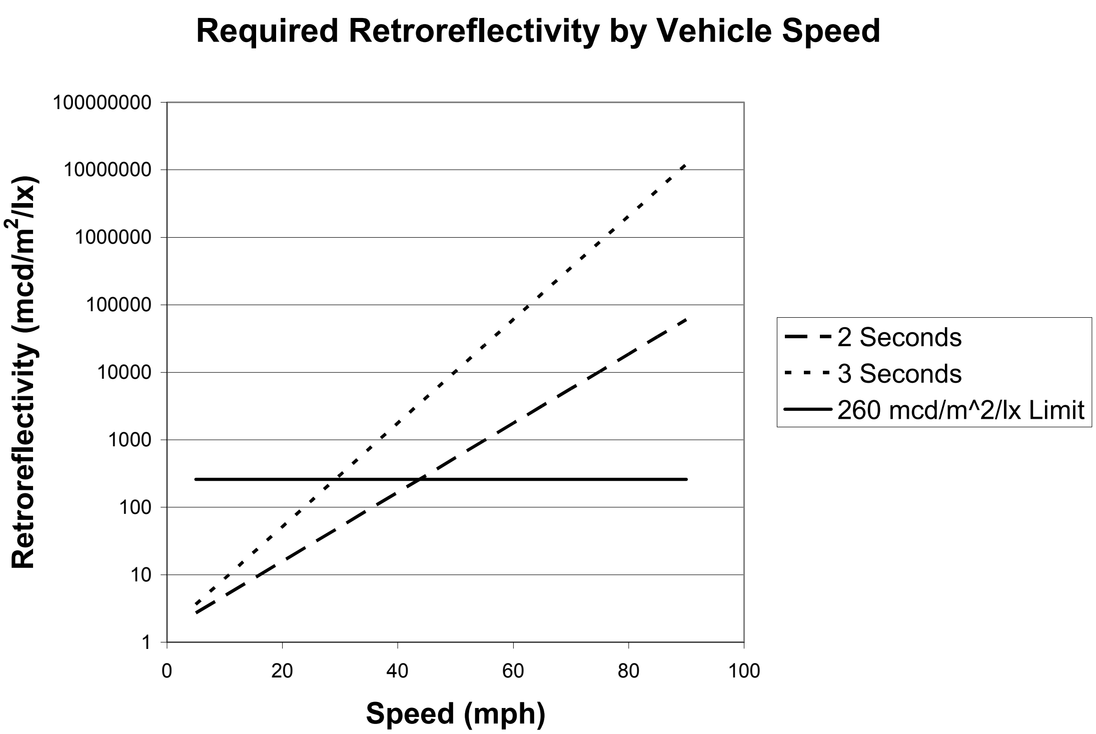


Figure 37. Modeled Threshold Retroreflectivity and by Vehicle Speed

As a minimum value for the recommendation of the retroreflectivity for pavement marking in wet conditions, 200 mcd/m^2/lx would be advisable. Although inadequate for higher speeds, it likely represents the highest payback in terms of driver and material performance. From the testing in this investigation, only the tape product performed to the level required by the driver. This material represented a mean increase of 125 ft (152 percent) in the visibility distance over the current VDOT-specified paint and small glass beads.

One of the results from the static experiment, however, is that the visibility distance performance of the standard paint with raised retroreflective pavement markers was superior to that of the wet night tape. This indicates that the RRPMs remain a valid marking solution for wet night conditions. The tape material has a significantly higher cost than the standard VDOT paint materials and using RRPMs may provide superior performance at a possibly lower cost. It should also be noted however that the RRPMs do not provide continuous delineation but are placed along the skip lines or centerlines, typically every 80 ft. This may reduce the effectiveness of the RRPMs in that added benefits may be achieved with continuous markings.

There are several limitations associated with this research. These limitations include the rain rate, the weathering of the pavement markings, and the retroreflectivity measurement method.

The rain rate may have limited the performance of some of the product types, compared to a more typical rain event. In this research, the rain rate chosen was a 95th-percentile event meaning that it was heavier rainfall than 95 percent of the rain events in the Commonwealth of Virginia. This rainfall rate will flood a pavement marking faster than a lighter rainfall and may limit the visibility of the different marking technologies. Similarly, the visibility through the simulated rate will also be limited by this heavier rain rate. Another factor to consider is the 6-percent slope of the road surface; this will allow the markings to drain more quickly than on a typical 2-percent crowned road. This issue may explain the unexpected performance results in the recovery testing.

Another limitation of this study method is that the markings were subjected to minimal traffic wear, although they were weathered for 30 days before testing. Normally, the retroreflectivity of a pavement marking will degrade after application due to the wear and tear from the vehicular traffic and accumulation of dirt on the marking surface. This issue is not deemed to be important as all of the markings were tested after 30 days of weathering.

Another potential limitation with these results is that the retroreflectivity calculations provided in this paper do not conform to ASTM 1710-97 geometries [5]. All ASTM methods require that measurements be made with "30-meter geometry." This geometry defines that all measurements of retroreflectivity be made with the observer at a distance of 30 m from the measurement point at a height of 1.2 m. The measurement distance for this experiment was the mean detection distance for each of the technologies. In the static experiment [1], it was found that the calculated and the measured retroreflectivity were highly correlated, which means that the use of the 30-meter geometry is suitable for the retroreflectivity measurements prescribed here.

A final limitation was the measurement technique used for the evaluation of the pavement markings under wet conditions. Similar to the 30-meter geometry issue, the static experiment showed a very high correlation of the continuous-wetting ASTM method 2176 [6] to the saturated marking measurement method used in this experiment. Due to this correlation, it is suggested that the current experimental method be considered for the evaluation of the wet pavement markings according to the results of this investigation.

CONCLUSIONS

- A log-linear relationship exists between the retroreflectivity and the detection distance. From this relationship, it appears that minimal additional benefit to the driver can be accomplished after a level of 200 cd/m2/lx is reached.
- A suggested 200 cd/m2/lx value does not however provide adequate detection distance for speeds over 45 mph.

RECOMMENDATION

1. *VDOT's Traffic Engineering Division should adopt an initial minimum retroreflectivity in wet conditions of 200 mcd/m^2/lx, measured in accordance with ASTM Standard 2176 for continuous wetting of pavement markings.* This value shows a maximum return to the driver in terms of visibility and is achievable with products available today. As part of implementing a performance-based specification on pavement marking retroreflectivity in wet night conditions, it will be necessary to develop guidelines or a policy regarding when such markings are to be used. A cost impact analysis should be included as part of this process; this analysis should include RRPMs as part of the current applications.

SUGGESTION FOR FURTHER RESEARCH

Further investigation into the retroreflectivity-distance model proposed in this paper should be made. Further refinements in the model are required to define the limits of the calculation. Extrapolating the model and the log-linear relationship indicates that the required retroreflectivity may never be achieved. High retroreflectivity materials as well as RRPMs can be used in a similar manner to the materials tested in this project to provide higher retroreflective limits to the model. This is required as the materials do not seem to provide adequate retroreflectivity at highway speeds. This conclusion may be due to the model used or it may indicate that higher performing materials are required.

COSTS AND BENEFITS ASSESSMENT

The implementation of the recommendation should:

- Provide greater visibility of the pavement marking to all drivers during wet night conditions.
- Improve usability of roadways during wet night conditions by improving lane and roadway delineation.
- Increase the safety of roadways by aiding in the reduction of run-off-road and lane-departure crashes during wet night conditions.

ACKNOWLEDGMENTS

The author wishes to acknowledge FHWA and VDOT for their support of this activity. Special thanks are extended to Benjamin Cottrell, VTRC, and Carl Andersen, FHWA, for their role as the project managers.

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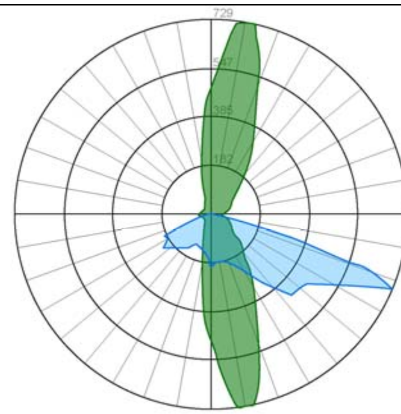
4. Schnell, T., Aktan, F., and Lee, Y.-C. Nighttime Visibility and Retroreflectance of Pavement Markings Under Dry, Wet, and Rainy Conditions. Paper presented at the 2003 Annual Meeting of the Transportation Research Board, Washington, D.C., January 2003.

5. ASTM International. Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer. Designation E1710-97. West Conshohocken, Pa., 1997.

6. ASTM International. Standard Method for Measuring the Coefficient of Reflected Luminance of Pavement Markings in a Standard Condition of Continuous Wetting. Designation E2176-01. West Conshohocken, Pa., 2001.

APPENDIX A.
ROADWAY LUMINAIRE DESCRIPTION

Luminaire	Usage in Study	Manufacturer and Part Number	Classification	Intensity Distribution
HPS 400	Crosswalk Lighting for Designs H20, H40, H60 Overhead Lighting	Hubbell Lighting RL-CD-40S38-021-250-M53	400 watt HPS M-C-II	

APPENDIX B.
WET VISIBILITY PROJECT PARTICIPANT SCREENING QUESTIONAIRE

Name ____ Male/Female
Phone Numbers ______________________________________
Best Time to Call ____________________________________
Screener____

Wet Visibility Phase II Driver Screening Questionnaire

Note to Researcher:
Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding eligibility for this study.

Introductory Statement:
After prospective participant calls or you call them, use the following script as a guideline in the screening interview.

Hello. My name is _____ and I'm a researcher with the Virginia Tech Transportation Institute in Blacksburg, VA. The project involves participation in a driving study to evaluate different types of pavement markings to aid motorists at night.

This study involves coming to the Transportation Institute 1 time for about 3 hours. You would help us evaluate different types of road markings by driving a semi (for those with a class A CDL) or a sedan (for those with standard driving license) on the Smart Road and answering questions. Participants will be paid $20.00 per hour. Does this sound interesting to you?

Next, I would like to ask you several questions to see if you are eligible to participate.

Questions

1. Do you have a valid driver's license?
   Yes _____ No _____

2. Do you have a Class A CDL?
   Yes _____ No _____

3. How old are you? ______ (stop if not 45 + years old for those with CDL or 65+ for those without a CDL.)

4. Are you eligible for employment in the United States?
   - Yes
   - No

5. How long have you held your regular drivers' license? ________________________________

6. Are you able to drive an automatic transmission without assistive devices or special equipment?
    - Yes
    - No

7. Have you had any moving violations in the past 3 years? If so, please explain.
    - Yes ____
    - No

8. Have you been involved in any accidents within the past 3 years? If so, please explain.
    - Yes ____
    - No

9. Do you have a history of any of the following? If yes, please explain.

Heart Condition	No____	Yes____________________________________
Stroke	No____	Yes____________________________________
Brain tumor	No____	Yes____________________________________
Head injury	No____	Yes____________________________________
Epileptic seizures	No____	Yes____________________________________
Respiratory disorders	No____	Yes____________________________________
Motion sickness	No____	Yes____________________________________
Inner ear problems	No____	Yes____________________________________
Dizziness, vertigo, or other balance problems	No____	Yes____________________________________
Diabetes	No____	Yes____________________________________
Migraine, tension headaches	No____	Yes____________________________________

10. (Females only, of course) Are you currently pregnant?

Yes _____ No _____ (If "yes" then read the following statement to the subject: "*It is not recommended that pregnant women participate in this study. However, female subjects who are pregnant and wish to participate must first consult with their personal physician for advice and guidance regarding participation in a study where risks, although minimal, include the possibility of collision and airbag deployment.")*

11. Do you have normal or corrected to normal hearing and vision? If no, please explain.

Yes _____

No _____ ____

12. Are you currently taking any medications on a regular basis? If yes, please list them.
    - Yes ____
    - No

I would like to take your name, phone number or phone numbers where you can be reached and hours/days when it's best to reach you.

Name ____ Male/Female

Phone Numbers ____

Best Time to Call ____

Criteria For Participation:

1. ***Must hold a standard valid driver's license for sedan condition or Class A CDL for truck condition.***
2. ***Must be 45 + years old if in the CDL condition.***
3. ***Must be 65+ years old if in the sedan condition.***
4. ***Must be eligible for employment in the U.S.***
5. ***Must drive at least 2 times a week. It does not matter what type of vehicle they drive 2x a week (i.e., if someone with a CDL drives their own personal sedan 2x a week, he/she is eligible).***
6. ***Must have normal (or corrected to normal) hearing and vision.***
7. ***Must be able to drive an automatic transmission without special equipment. This applies to those in both sedan and CDL conditions.***
8. ***Must not have more than two driving violations in the past three years.***
9. ***Must not have caused an injurious accident in the past two years.***
10. ***Cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, current respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.***
11. ***Cannot currently be taking any substances that may interfere with driving ability (cause drowsiness or impair motor abilities).***

APPENDIX C.
WET VISBILITY INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of the Project: Evaluation of pavement marking visibility in wet night conditions from different Dynamic vehicles

INVESTIGATORS: Ronald B. Gibbons and Jonathan M. Hankey

I. THE PURPOSE OF THE RESEARCH

Pavement markings convey regulations and warnings, and provide tracking information and guidance to the driver. Much of the visual information needed by a driver to navigate safely in a variety of conditions including darkness, and adverse weather, is provided by pavement markings. The purpose of this research is to evaluate the visibility of different types of pavement markings in wet weather conditions.

II. PROCEDURES

During the course of this experiment you will be asked to perform the following tasks:

1) Read and sign an Informed Consent Form.
2) Show a valid standard driver's license or Class A CDL.
3) Complete vision tests.
4) Drive a sedan (or semi truck if you have a Class A CDL) on the Smart Road.
5) Adhere to the speed limit of not more than 25 miles per hour when not in the rain and not more than 20 miles per hour when in the rain.
6) Listen to the instructions regarding any tasks you may perform.

It is important for you to understand that we are evaluating the various pavement markings, not you. Any tasks you perform or opinions you have will only help us do a better job of developing guidelines for the use of pavement markings. Therefore, we ask that you perform to the best of your abilities. The information and feedback that you provide is very important to this project.

III. RISKS

There are risks or discomforts to which you may be exposed in volunteering for this research. They include the following:

1. The risk of an accident normally associated with driving an unfamiliar automobile in the rain at less than 25 miles per hour, on straight and slightly curved roadways.

2. Possible fatigue due to the length of the experiment. However, you may take rest breaks during the experimental session.
3. If you are driving the sedan and have had previous eye injuries, you may be at an increased risk of further eye injury by participating in a study where risks, although minimal, include the possibility of collision and airbag deployment.

The following precautions will be taken to ensure minimal risk to you.

1. You and the in-vehicle experimenters will be required to wear the lap and shoulder belt restraint system while in the car.
2. The sedan is equipped with a driver's side airbag supplemental restraint system.
3. The semi truck and sedan are equipped with a fire extinguisher and first-aid kit.
4. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to the driver in any foreseeable case.
5. Data collection will be cancelled in the event of severe weather.
6. If you are pregnant, you have reviewed this consent form with your obstetrician and discussed the risks of participating in this study with him/her. You are willing to accept all possible risks of participation.
7. You do not have any medical condition that would put you at a greater risk, including but not restricted to epilepsy, balance disorders, and lingering effects of head injuries and stroke.
8. In the event of a medical emergency, or at your request, VTTI staff will arrange medical transportation to a nearby hospital emergency room.

In the event of an accident or injury in an automobile, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, workers compensation does not apply to volunteers; therefore, if not in an automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses.

IV. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Subject participation may have a significant impact on future guidelines for roadways.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You will be allowed to see your data and withdraw the data from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed. A digital video and audio recording will be made while you are driving in the experimental vehicle. These recordings will not be released to any other party without your written consent. At no time will VTTI researchers release data identifiable to you without your written consent.

VI. Compensation

You will receive $20.00 per hour for your participation in this study. This payment will be made to you at the end of your voluntary participation in this study. If you choose to withdraw before completing all scheduled experimental conditions, you will be compensated for the portion of time of the study for which you participated.

VII. Freedom to Withdraw

As a participant in this research, you are <u>free to withdraw at any time</u> for any reason. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any questions or respond to any research situations without penalty.

VIII. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained.

IX. Participant's Responsibilities

- To follow the experimental procedures as well as you can.
- To inform the experimenter if you have difficulties of any type.
- To wear your seat and lap belt.
- To abide by the speed limit and traffic laws.
- To abstain from any substances that will impair your ability to drive.
- To drive the test vehicle in a safe and responsible manner.

X. Participant's Acknowledgments:

If you are driving the sedan, check one of the following:

- ☐ I have **not** had an eye injury/eye surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery).
- ☐ I **have** had an eye injury/eye surgery and I've have been informed of the possible risks to participants who have had eye surgery. I choose to accept this possible risk to participate in this study.

Check one of the following:

- ☐ VTTI **has my permission** to give audio recordings and digital video including my image to the client who has sponsored this research. I understand that the client will only use the videotape for research purposes.
- ☐ VTTI does not have my permission to give audio recordings and digital video including my image to the client who has sponsored this research. I understand that VTTI will maintain possession of the recordings, and that it will only be used for research purposes.

XI. Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I understand that I may withdraw at any time without penalty. I agree to abide by the rules of this project.

______________________________________ ______________________

Participant's Signature Date

Should I have any questions about this research or its conduct, I may contact:

Jon Hankey	(540) 231-1500
Ron Gibbons	(540) 231-1500
David Moore, Chair, IRB	(540) 231-4991

______________________________________ ______________________

Experimenter's Signature Date

APPENDIX D.
WET VISIBILITY PRE-DRIVE QUESTIONAIRE

Participant Number ___________

Pre-Evaluation Questionnaire

1. How long have you had your driver's license?

   ____

2. How many miles/year do you drive?

   ____

3. How far have you driven in the last 2 years (miles)?

   ____

4. Please indicate approximately how often you drive at night *(Please check only one)*
   - O Every night
   - O Three times per week
   - O Once per week
   - O Less often that one time per week

5. Have far do you drive at night regularly (miles)?

   ____

6. Would you say you drive at night with: *(Please circle only one)*

   no difficulty | *little difficulty* | *some difficulty* | *moderate difficulty* | *extreme difficulty*

7. In general, how do you feel about driving at night in good weather? *(Please circle only one)*

   very comfortable | *somewhat comfortable* | *neither comfortable nor uncomfortable* | *somewhat uncomfortable* | *very uncomfortable*

8. Please indicate approximately how often you drive at night in typical rain conditions? *(Please check only one)*
   - O Every night
   - O Three times per week
   - O Once per week
   - O Less often that one time per week

9. Would you say you drive at night in typical rain conditions with: *(Please circle only one)*

no difficulty	*little difficulty*	*some difficulty*	*moderate difficulty*	*extreme difficulty*

10. In general, how do you feel about driving at night in typical rain conditions? *(Please circle only one)*

very comfortable	*somewhat comfortable*	*neither comfortable nor uncomfortable*	*somewhat uncomfortable*	*very uncomfortable*

11. What vehicle do you most often drive at night?

    Make _______________

    Model _______________

    Year _____________

12. Do you wear corrective lenses while driving?

    YES NO

    If Yes, these are:
   - O Single vision eyeglasses
   - O Bifocal eyeglasses
   - O Trifocal eyeglasses
   - O Graduated Focus eyeglasses
   - O Contact lenses

13. What are you most concerned about when driving in bad weather at night?