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The Refinement of Drivers' Visibility Needs During Wet Night Conditions: Wet Visibility Project Phase III

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Final Report VCTIR 11-R20

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The purpose of this project was to develop a specification for the minimum retroreflectivity of pavement markings in wet nighttime conditions. In order to establish this specification, the performance of four retroreflective pavement marking materials in wet-night conditions was evaluated. The performance of the pavement markings was evaluated by driver participants under simulated rain conditions using a similar protocol to studies that have already been performed at the Virginia Tech Transportation Institute. The performance of the markings was verified based on the participants' ability to detect the end points of the markings in both rainy and clear conditions.

The conclusions from this investigation indicate the following:

- The materials developed over recent years show an improved performance over those tested previously. These materials provide adequate performance through improved technology and performance.
- The log-linear relationship found previously is functional for the data provided. Two models were developed. The model with no intercept provides a more constrictive boundary at low levels of retroreflectivity.
- A retroreflectivity value above 250 mcd/m^2/lx provides limited return in terms of detection distance.
- A specification limit of 150 mcd/m^2/lx will provide adequate visibility for 55 mph in dry conditions and 40 mph in wet conditions using standard dry retroreflectivity measurements, and 1 in/hr measurements for the wet conditions. This value should be the minimum maintained over the life of the marking.
- The retroreflectivity specification for a white and a yellow material should be equal.
- The rumble stripe showed a significant recovery time improvement over the other tested materials.

This study recommends a minimum retroreflectivity of 150 mcd/m^2/lx for white and yellow pavement markings in both dry and wet nighttime conditions. This level provides the Virginia Department of Transportation with the basis for establishing a performance-based specification for pavement markings.

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FINAL REPORT

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ABSTRACT

The purpose of this project was to develop a specification for the minimum retroreflectivity of pavement markings in wet nighttime conditions. In order to establish this specification, the performance of four retroreflective pavement marking materials in wet-night conditions was evaluated. The performance of the pavement markings was evaluated by driver participants under simulated rain conditions using a similar protocol to studies that have already been performed at the Virginia Tech Transportation Institute. The performance of the markings was verified based on the participants' ability to detect the end points of the markings in both rainy and clear conditions.

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- The materials developed over recent years show an improved performance over those tested previously. These materials provide adequate performance through improved technology and performance.
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INTRODUCTION

This project is the follow-on to a previous multi-phased project entitled "Visibility Needs of Drivers under Wet Night Conditions." The primary purpose of the previous project, in its entirety, was to determine the visibility needs of motorists during wet nighttime conditions. Those findings were then used to develop performance measures for evaluating wet nighttime retroreflectivity of pavement delineation devices. The original project was undertaken in six phases (Gibbons et al., 2004; Gibbons, 2006).

The first phase of the first project established a typical rain event for Virginia, which then determined the target rain level for the testing phase of the project. The second phase involved the static testing of the pavement markings under the developed rain condition. In the static testing, the participants were asked to view the road from a stationary vehicle and to count the number of visible pavement markings. This method allowed for the development of a visibility distance for each of the different technologies. However, because the experiment was static, the results may not accurately model the visibility of the pavement markings during a driving task. Phases III through VI of the first project involved a dynamic test that took place on the Virginia Smart Road. In this test, driver behavior was measured in addition to marking visibility distances. These dynamic results allowed for the development of performance standards for pavement markings under wet conditions.

In the original project, only one material met the developed visibility requirements, which created some difficulty. The developed minimum retroreflectivity level of 200 mcd/lx was based on a white marking material and may only apply to roadway speeds of less than 55 mph. In addition to this limitation, the application of this requirement to yellow markings may not be valid.

Since the completion of the original wet visibility project, further research has resulted in new methods for the evaluation of the pavement markings. These developments include a new spray methodology for evaluation of the pavement marking technology. This method was tested at an on-road test site on I-10 in Florida. Similarly, new pavement marking materials and methods have been developed that require evaluation. Rumble stripes (i.e., rumble strips with a painted line), temporary tape products, different retroreflective elements, and polyurea materials all merited investigation.

Another project conducted in parallel with this project is an on-road assessment of various pavement marking products. This analysis will include durability and driver perception experiments in natural rain. The project documented here is the assessment of the same technologies in a controlled environment. This controlled testing provided forward compatibility with the previous projects and allowed for the testing of other materials that cannot be included in the parallel on-road experiment.

PURPOSE AND SCOPE

The purpose of this project was to establish a performance specification for pavement marking materials in wet nighttime conditions and to evaluate the new retroreflectivity testing methods based on the drivers' visual performance. In order to establish this specification, the performance of four retroreflective pavement marking materials in wet-night conditions was evaluated. The performance of the pavement markings was evaluated by driver participants under simulated rain conditions using a similar protocol to studies that have already been performed at the Virginia Tech Transportation Institute (VTTI). The performance of the markings was verified based on the participants' ability to detect the end points of the markings in both rainy and clear conditions.

METHODS

Experimental Design

The experimental design used in this project consisted of a 2 x 2 x 3 x 4 x 2 mixed-factors design. The factors and the levels are described here.

Between-Subjects Variables

- Gender (2 levels): Female, Male. The gender independent variable was chosen in order to generalize the results of this study to a broad user population. This factor was used for balance only; it was not used in the data analysis.

- Participant Age (2 levels): Younger (18-34 years old) and Older (65 years old and above). The younger and older age groups were selected to investigate the changes in vision and perception that may occur with increasing age.

- Weather Condition (3 levels): Dry, Raining, Recovery. While the intent of the study was to evaluate pavement marking performance in the rain, a subset of participants performed the study in dry conditions so a comparison to a control group could be made. The Recovery condition was included to evaluate how the markings perform during recovery. It should be noted that the recovery could only be collected at the end of an experimental session.

Within-Subjects Variables

- Marking (4 levels): 3M white wet-reflective tape, 3M yellow wet-reflective tape, Ennis High Build paint in a rumble strip, Epoplex Glomarc 90. These pavement markings were chosen so a variety of pavement marking types could be evaluated. A more detailed description of each marking can be found in the pavement materials section of this report.

- End Point (2 levels): Start, Stop. Participants were asked to identify the end of a pavement marking as a stop or start so the in-vehicle experimenter could be sure which part of the line the participant was seeing. This differentiation was included in the analysis to see if it had any effect on detection.

Experimental Design Matrix

The mixed-factorial experimental design is shown in Table 1. Twelve participants from each age group (subjects 1 through 24) performed the study in wet conditions, and six from each age group (subjects 25 through 36) performed the study in dry conditions. Each age group consisted of an even number of males and females.

Table 1. Mixed-factorial experimental design matrix.

Pavement Marking	Road Condition	Younger		Older		Total Observations
		Female	Male	Female	Male	
3M White Tape	Raining	S1 - S6	S7 - S12	S13 - S18	S19 - S24	24
	Recovery	S1 - S6	S7 - S12	S13 - S18	S19 - S24	24
	Dry	S25 - S27	S28 - S30	S31 - S33	S34 - S36	12
3M Yellow Tape	Raining	S1 - S6	S7 - S12	S13 - S18	S19 - S24	24
	Recovery					0
	Dry	S25 - S27	S28 - S30	S31 - S33	S34 - S36	12
Ennis High Build Paint	Raining	S1 - S6	S7 - S12	S13 - S18	S19 - S24	24
	Recovery	S1 - S6	S7 - S12	S13 - S18	S19 - S24	24
	Dry	S25 - S27	S28 - S30	S31 - S33	S34 - S36	12
Epoplex Glomarc 90	Raining	S1 - S6	S7 - S12	S13 - S18	S19 - S24	24
	Recovery	S1 - S6	S7 - S12	S13 - S18	S19 - S24	24
	Dry	S25 - S27	S28 - S30	S31 - S33	S34 - S36	12

Presentation Order

Participants observed each pavement marking in the same order. Table 2 shows the order in which markings were seen. The pattern shown for the first two laps repeated for laps 3 through 8. The first marking for each lap alternated between the Ennis High Build paint and the 3M yellow tape. Both of these markings were installed on the same section of roadway, and

Table 2. Pavement marking presentation order.

Lap	Direction	Marking
1	Downhill	Ennis High Build in Rumble Strip
		3M White Tape
		Epoplex Glomarc 90
	Uphill	Epoplex Glomarc 90
		3M White Tape
2	Downhill	3M Yellow Tape
		3M White Tape
		Epoplex Glomarc 90
	Uphill	Epoplex Glomarc 90
		3M White Tape
Recovery	Downhill	Ennis High Build in Rumble Strip
		3M White Tape
		Epoplex Glomarc 90
	Uphill	Epoplex Glomarc 90
		3M White Tape

participants were asked to focus on only one of them for each lap, so there would be no confusion. For the final Recovery lap, it was decided that all participants would observe the Ennis High Build paint rather than the 3M yellow tape for several reasons. The first is because of the time-sensitive nature of recovery testing. Had a second recovery lap been made, the results would have been greatly affected by the increased time for water to run off of the marking. The second reason was that the rumble strip in which the Ennis High Build paint was installed was of particular interest for recovery conditions. This was the only marking installed in a rumble strip, so it was important to collect recovery data for it. The final reason was that recovery data were recorded for another 3M tape marking, and it was expected that the recovery performance would be similar.

Dependent Variables

Detection Distance

As a measure of the visibility of the pavement markings, the distance at which participants could see the start or the end of a line was recorded. The ends of the markings were simulated by covering portions of the line using black roofing material, creating the illusion that there were gaps in the pavement markings. When a participant could first see the end of a line, he/she would verbally identify it by saying “stop” if the line was coming to an end or “start” if the line was beginning again. The in-vehicle experimenter would press a button when the participant identified a “stop” or “start,” and again when the vehicle reached the actual start and end point on the road. These buttons flagged the data so that during later analyses the distance traveled between those two points could be determined. This distance was called the Detection Distance for that particular marking. Figure 1 illustrates this process.

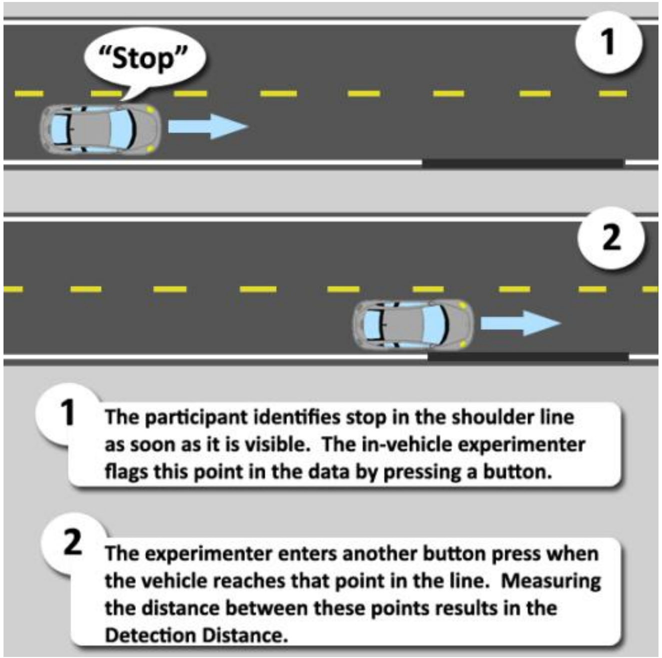

Figure 1. Method for recording Detection Distance.

Participants

Thirty-six participants were selected to participate in this study. Participants were selected from two age categories: younger (18-34 years old) and older (65+). Twelve participants from each age group performed the study in wet conditions, and six from each age group performed the study in dry conditions. Each group of participants consisted of an even number of males and females. Virginia Tech Institutional Review Board (IRB) approval was obtained prior to recruiting subjects. Recruitment occurred through the VTTI participant database, a poster (Appendix A) and also through word-of-mouth. A general description of the study was provided to the subjects over the phone before they decided if they would like to participate. If they were interested, subjects were then screened with a verbal questionnaire to determine whether they were licensed drivers and whether they had any health concerns that should exclude them from participating in the study (Appendix B). If subjects were determined to be eligible for the study, they would then be scheduled to come to VTTI for participation. When subjects arrived at VTTI, they read and signed an informed consent form (Appendix C). Subjects were paid $20/hr and were allowed to withdraw at any point in time, with compensation adjusted accordingly.

It is noteworthy that due to winter conditions, one half of the participants were evaluated before the winter and the other half were evaluated after the winter. The impact of this seasonal change is considered in the data analysis.

Facilities and Equipment

Virginia Smart Road

The experiment took place at VTTI and on the Virginia Smart Road in Blacksburg, Virginia. The Smart Road is a 2.2-mile two-lane controlled access road.

The markings were installed on the Smart Road. Two of the technologies were installed on the main portion of the Road and two of the technologies were installed on an auxiliary road portion. This auxiliary road portion was used for the installation of the rumble stripes and the yellow markings. The auxiliary roadway was used to maintain the integrity of the main portion of the Smart Road.

Figure 2 illustrates the Smart Road, the path that participants drove for the study, and the sequence for each lap driven.

Test Vehicles

Subjects drove a 2003 model Chevy Malibu with halogen low beams (Figure 3). An in-vehicle experimenter rode in the back seat for the duration of the study. Each Malibu was equipped with a Data Acquisition System (DAS) that recorded vehicle network data and four camera views inside and around the vehicle. The DAS, shown in Figure 4, recorded the driving distance and the button presses for the Detection Distance calculations. The DAS also recorded information entered by the experimenter such as the participant's age, subject number, and button presses. In addition, each vehicle was equipped with a luminance camera system that took specialized photos throughout the study. These photos allowed for the measurement of the luminance of any object captured in the forward view of the vehicle.

Pavement Markings

Four types of pavement markings were tested in this study. They are listed here in alphabetical order. The following images of the pavement markings were taken after the completion of the experiment. Note that these materials were chosen to be representative of a technology and not for a specific product performance evaluation.

3M White Wet-Reflective Tape: The 3M white wet-reflective tape (Figure 5) was installed on both shoulder lines on the two-lane Smart Road. Each line was surface-applied and approximately 500 feet in length. This marking is referred to as "white tape" throughout the rest of this document.

3M Yellow Wet-Reflective Tape: The 3M yellow wet-reflective tape (Figure 6) was installed on the left shoulder of the single-lane auxiliary road. The line was surface-applied and approximately 1,000 feet in length. This marking is referred to as "yellow tape" throughout the rest of this document.

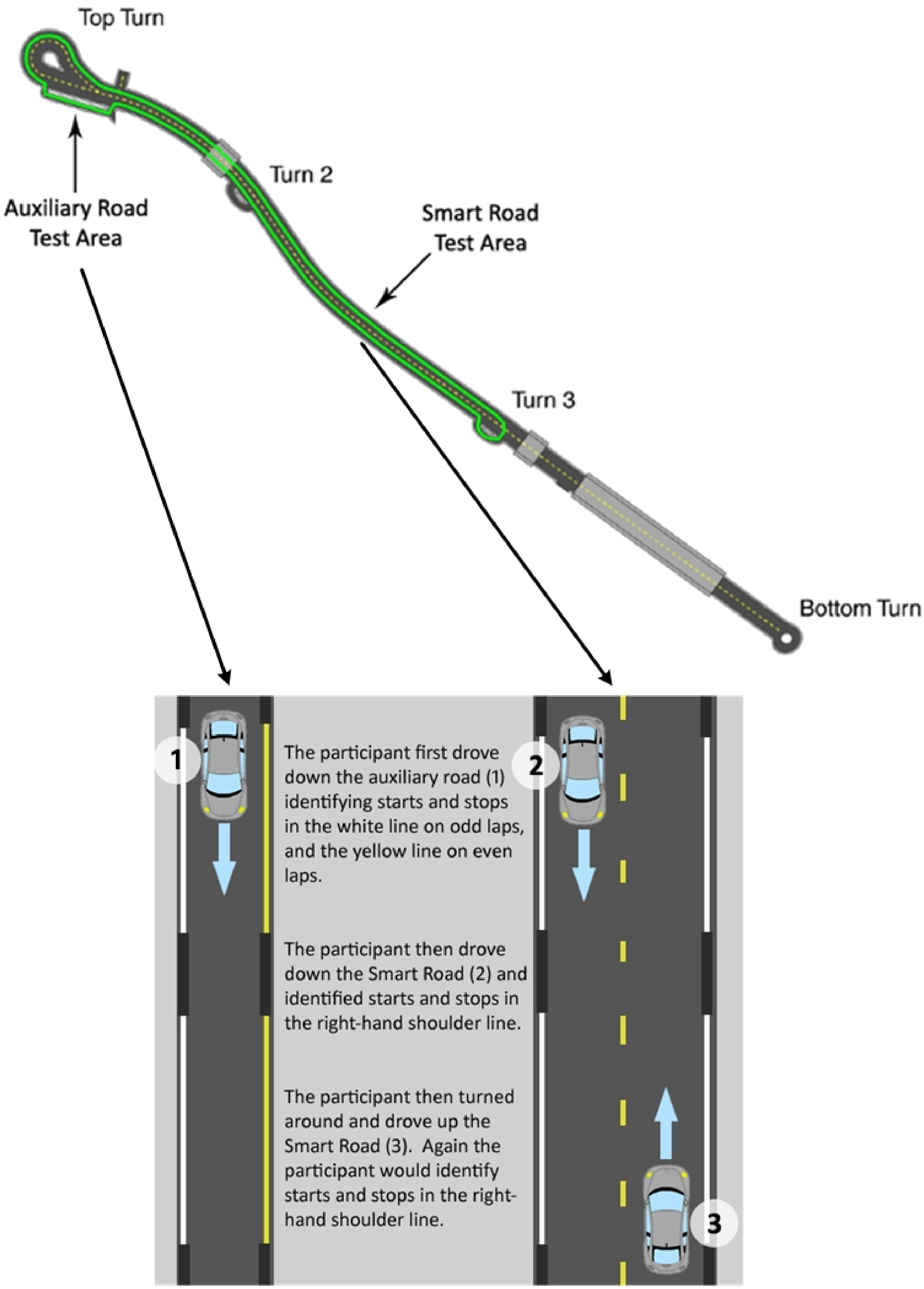

Figure 2. Path driven by each participant and presentation methodology on the Smart Road.

Figure 3. 2003 Chevy Malibus driven by participants.

Figure 4. Data Acquisition System in the trunk of the participant vehicle.

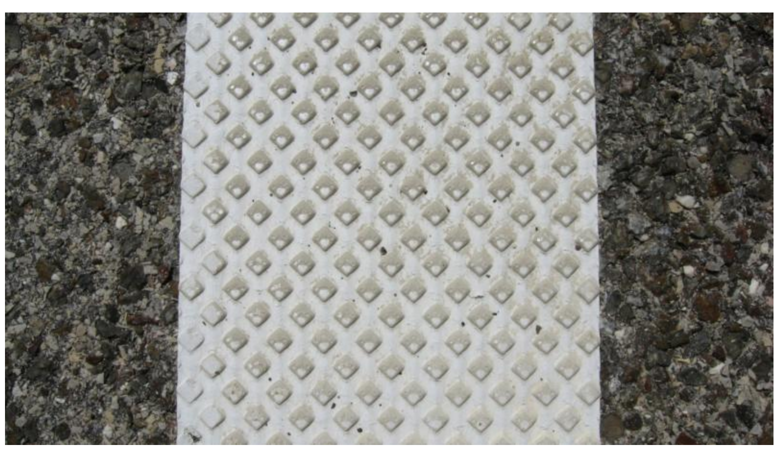

Figure 5. 3M white wet-reflective tape.

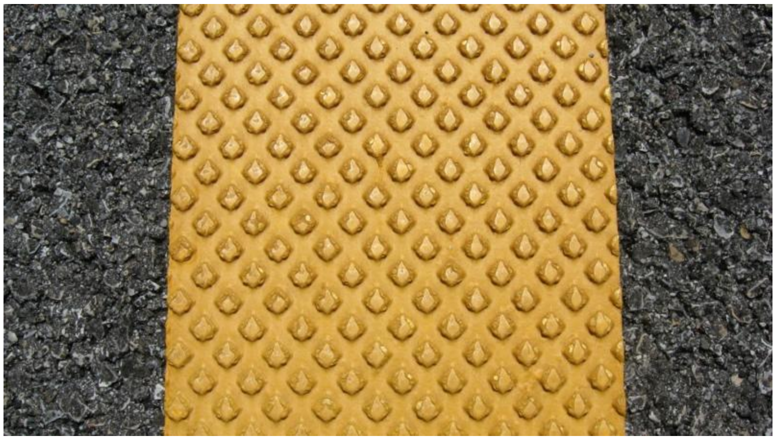

Figure 6. 3M yellow wet-reflective tape.

Ennis High Build Paint: The Ennis High Build paint (Figure 7) was installed on the right shoulder of the single-lane auxiliary road. The line was installed in a rumble strip and was approximately 1000 feet in length. This marking is referred to as "paint in a rumble strip" throughout the rest of this document.

Figure 7. Ennis High Build paint.

Epoplex Glomarc 90: The Epoplex Glomarc 90 (Figure 8) was installed on both shoulders of the two-lane Smart Road. Each line was surface-applied and approximately 500 feet in length. This marking is referred to as "polyurea" throughout the rest of this document.

Figure 9 illustrates the location of each marking, and how the participant vehicle approached each section.


Figure 8. Epoplex Glomarc 90.

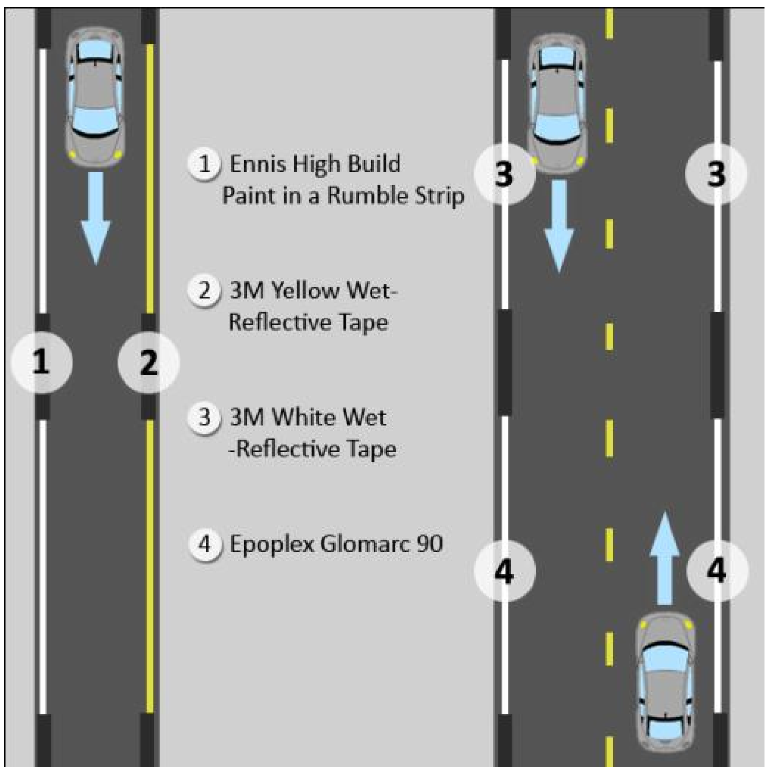

Figure 9. Pavement marking locations.

Experimental Procedure

Participants were initially screened over the telephone (Appendix B). If eligible for the study, a time was scheduled for testing. Participants were instructed to meet an experimenter at VTTI in Blacksburg, Virginia. Participants were scheduled in pairs. Upon arriving at VTTI, each participant was asked to read and sign the Informed Consent (Appendix C), fill out a W9 tax form (Appendix D), a health questionnaire (Appendix E), and a pre-drive questionnaire (Appendix F). Several vision tests were then administered to each participant. A participant's visual acuity was determined using a Snellen chart (Appendix E). A minimum score of 20/40 vision, which is the legal minimum to hold a driver's license in Virginia, was required for further participation. Each participant was also tested for sensitivity to glare by reading the Snellen chart while looking through a Brightness Acuity Tester (BAT). The BAT uses a small light to present glare to a participant's eye. Participants would read the chart one eye at a time for each brightness setting: off, low, medium, and high. Participants were also tested for contrast sensitivity by looking at a chart and indicating the direction of lines of varying degrees of contrast and frequency. Finally, participants were tested for color blindness by indicating what numbers they could see on several pages of a color blind test.

Once all forms and vision tests were complete, the experimenter would orient the participant to the study. The following script was read to each participant:

> *Tonight you will drive an experimental vehicle on the Smart Road. The primary interest of this study is the visibility of pavement markings in wet night conditions. To determine the visibility of the pavement markings, we are going to cover up portions of the line, and we'd like you to identify when you can first see the lines either stop or start.*

Participants were then shown a diagram to help them visualize what was meant by a line stopping and starting (Figure 10).

> *If you see a line come to a stop like this, say "stop." If you see the line start up again like this, say "start." It's important that you say "stop" or "start" as soon as you see it. We are interested in how far away the starts and stops are visible. I'd also like you to watch for a white cone that may be placed on the center dash line. When you see the cone, say the word "cone."*

Participants were asked to identify a white cone placed in the middle of the road to encourage a normal scanning behavior and to prevent them from simply staring at the shoulder line.

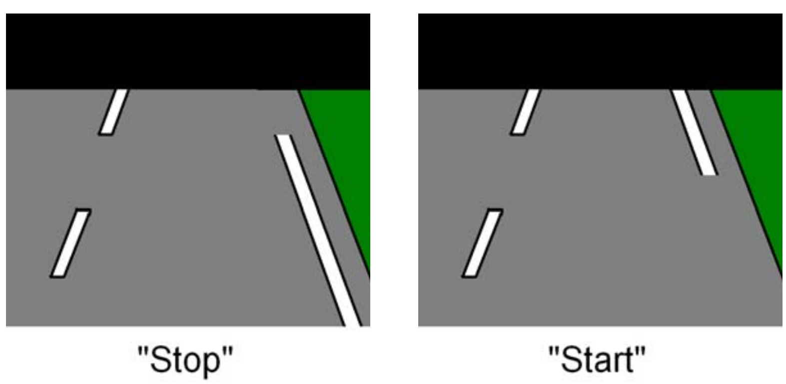

Figure 10. Stop and Start diagrams.

Once participants had been oriented to the study, each in-vehicle experimenter would escort his assigned participant to the experimental vehicle. The vehicles were designated as Vehicle 1 and Vehicle 2. The in-vehicle experimenter would familiarize the participant with the vehicle controls, such as seat and mirror adjustments and wiper controls. While the participant got into a comfortable driving position, the in-vehicle experimenter started up the DAS. Once the participant and computer systems in each vehicle were ready, the experimenters would instruct the participants to exit the parking lot and drive to the Smart Road.

Once on the Smart Road, participants were instructed to stop in the top turnaround while the in-vehicle experimenters read the instructions for the practice lap. The practice lap was performed to familiarize the participants with the vehicle and the route they would be driving on the Smart Road. In addition, the in-vehicle experimenters would answer any questions the participants had. No pavement markings were covered during the practice lap, and participants were not asked to identify any starts or stops.

In order to keep the two participant vehicles safely separated during each lap, the Vehicle 1 participant would begin a lap while the Vehicle 2 participant waited. After roughly 30 seconds, or once Vehicle 1 exited the auxiliary road, the Vehicle 2 participant was instructed to begin. When Vehicle 1 reached the lower turnaround location, the experimenter instructed the participant to wait until Vehicle 2 also reached the turnaround before going back up the road. This prevented the two vehicles from ever passing each other going in opposite directions. When going back up the road, the Vehicle 2 participant would wait until Vehicle 1 was out of sight before proceeding.

After the practice lap was complete, the test laps began. Each participant drove eight test laps during which they identified starts and stops in the lines. Participants were asked to drive at 20 mph, and the in-vehicle experimenter would remind them to maintain this speed if they started driving too fast or too slow. For the single-lane auxiliary road, participants alternated looking for starts and stops in the white line (during odd-numbered laps) and the yellow line (during even-numbered laps). For participants completing the study in the rain, one final lap was recorded. This lap—called the recovery lap—was completed with the rain turned off. Participants completing the study in dry conditions did not perform the recovery lap.

Once all laps were complete, participants were instructed to exit the Smart Road and return to the VTTI parking lot. From there, the experimenters escorted each participant back inside. Participants were then given a copy of the informed consent form and a receipt showing their time of participation and how much compensation they would receive. Participants earned $20 per hour, and were mailed a check within two weeks of participation.

Retroreflectivity

In addition to the human-subjects experiment, the retroreflectivity of the markings was recorded at different intervals after installation in order to assess each marking's performance over time. Retroreflectivity was recorded for four conditions: Dry (American Society of Testing and Materials [ASTM] 1710), the "Bucket Test" (ASTM 2177), 1 in/hr rain, and 2 in/hr rain. The retroreflectivity was measured using an LTL-X retroreflectometer (Figure 11), and the rain conditions were created by using a rain box built by VTTI (Figure 12) according to specification from ASTM WK 19806.

Figure 11. LTL-X Retroreflectometer.

Figure 12. VTTI's rain box.

The Dry condition would be recorded first. The LTL-X was placed on a predetermined spot on the marking facing in the direction of traffic flow, and three readings were taken. The Bucket Test was performed next by soaking the line in front of the LTL-X with water from a tank in the back of a pickup truck. A hose coming from the tank was held over the line, and water was poured for several seconds in order to ensure the entire area was saturated. After about 45 seconds, three measurements were taken roughly 2 seconds apart. For the continuous rain method, the rain box was placed over the line in front of the LTL-X, and the 1 in/hr nozzle was turned on. After about 30 seconds, measurements were taken with the LTL-X approximately every 2 seconds until three consistent (maximum +/- 10%) readings were found. The last three readings were recorded. The rain box was then switched to the 2 in/hr nozzle. After another 30 seconds, measurements were taken approximately every 2 seconds until three consistent readings were found. Those three readings were then recorded.

This process was repeated three times for each marking section; measurements were made at the beginning, middle, and end of each marking section. The three readings for each condition and each location on a marking were averaged together to come up with an overall average for each condition. These tests were performed twice: 3 months after the installation of the markings, and once again 11 months after installation. The results of this testing will be discussed after the results of the human-subjects experiment.

The method used to measure the retroreflectivity of the Ennis High Build paint in the rumble strip differed from the methods laid out by ASTM International. The E1710-05 designation states that the correct method is to average several measurements taken over one cycle of the rumble strip. However, for this study, measurements were taken at the point along the cycle that resulted in the highest values. This deviation from the ASTM method was made because the highest retroreflectivity and therefore luminance would be the most visible portion of the marking and would be more highly correlated to the visibility experiments.

Luminance Camera Image Analysis

In addition to these methods, an analysis of the luminance camera images was conducted to determine the retroreflectivity of the pavement markings at the moment participants detected a start or stop in the line. Using a custom-made MATLAB program, the luminance of the end point was determined by loading the image that was taken at the moment a participant detected it, and cropping out the end of the marking. This returned a mean luminance for the selected area. Figure 13 shows an example of an image taken from the luminance camera.

Next, the vertical illuminance of the marking was measured. As the data collection activity was from a moving vehicle and measured at the pavement marking there was no means of measuring it during the study and, thus, this value had to be predicted. This was performed by first measuring the vertical illuminance provided by the headlamps of one of the Malibus used in the study. The illuminance at the right edgeline was measured every 25 feet for a range of 25 to 300 feet. These data were used to produce a model for predicting the illuminance based on detection distance. The data and the regression line are shown in Figure 14 along with the associated function and R^2 value.

This provided a predicted level of vertical illuminance, which was adjusted to account for the angle at which participants viewed the markings. The following equation was used to transform the data, in which E_V is the vertical illuminance, h is the height of the headlamps, and d is the distance to the marking; which, in this case, is detection distance:

$$E_P = E_V / \cos(\tan^{-1}(h/d))$$

Finally, the resulting illuminance value E_P was used with the luminance value attained from the luminance camera image to calculate the retroreflectivity. The following equation was used:

$$Retroreflectivity = Luminance / Illuminance * 1000$$

Figure 13. Luminance camera image.

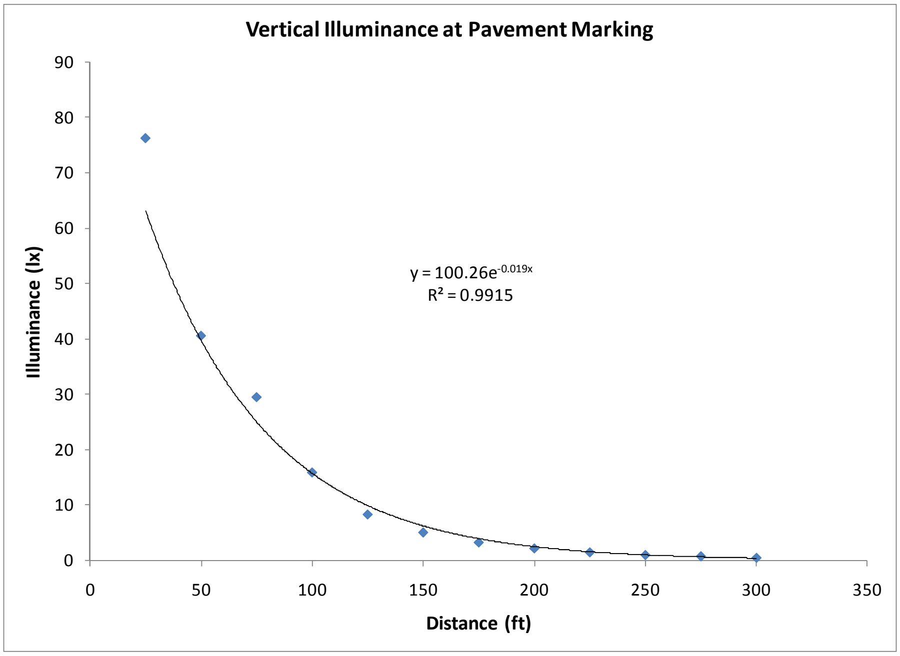

Figure 14. Vertical illuminance at pavement marking.

Data Analysis

Four separate analyses were conducted. The analyses were broken down by condition with the first being for Raining conditions, the second for Recovery conditions, the third for Dry conditions, and the final analysis consisting of all three conditions. An analysis of variance (ANOVA) with a significance level of 95% ($\alpha = 0.05$) was used in each case.

RESULTS

Detection Distance

The Detection Distance was first considered as an ANOVA considering all of the experimental design parameters. The results from this ANOVA are summarized in Table 3. The significant factors are denoted by an asterisk and the associated F values are shown.

Table 3. ANOVA results for Detection Distance (all).

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig.
Participant Age	1	745847.6142	745847.6142	11.65	0.0018	*
Marking Type	3	245155.1784	81718.3928	22.49	<.0001	*
Participant Age*Marking Type	3	5931.295	1977.0983	0.54	0.6533	
Weather Condition	1	820090.4173	820090.4173	201.57	<.0001	*
Participant Age*Weather Condition	1	27814.677	27814.677	6.84	0.0158	*
Marking Type*Weather Condition	2	11556.05756	5778.02878	3.48	0.0398	*
Participant Age*Marking Type* Weather Condition	2	5134.36602	2567.18301	1.54	0.225	
	13	1861529.605				
**p < 0.05 (significant).*						

Within this analysis, Participant Age, Marking Type, and Weather Condition were all found to be significant main effects. The interactions of Participant Age and Weather Condition, and Marking Type and Weather Condition were also found to be significant. Figure 15 shows the mean Detection Distance for each age group. Younger participants were able to detect the line starts and stops at significantly longer distances. This is expected due to the changes in vision associated with aging, as aging eyes have lower contrast sensitivity than younger eyes.

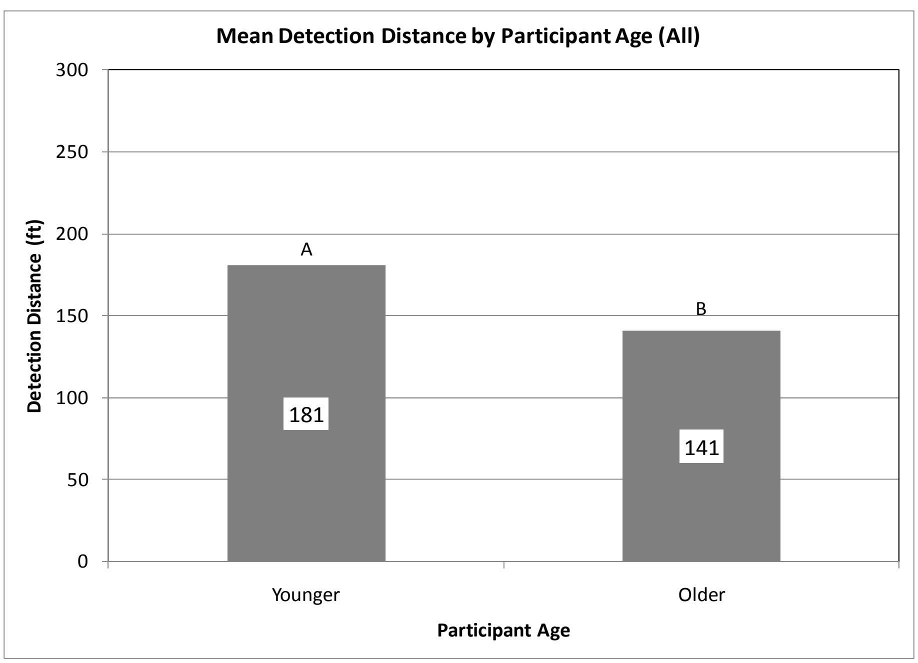

Figure 15. Mean Detection Distance by Participant Age (all).

Marking was also found to be significant (Figure 16). When considering all conditions, we see that each marking is significantly different from each other marking, with the white tape having the longest Detection Distances, and the yellow tape having the shortest. This figure represents the overall performance of the materials in all conditions and can be considered as the general performance factor. It should be noted that the yellow material was not measured in recovery and those data are not represented here. It also should be noted that while the materials were found to be significantly different, the overall practical difference is only 24 feet from the highest performing to the lowest performing.

For the weather condition results, shown in Figure 17, Dry conditions produced significantly higher Detection Distances than Recovery or Rain, and Rain had the lowest distances. This was expected as the weather conditions are known to reduce marking visibility. This marking visibility reduction includes both the impact of the rain and the flooding of the marking material. The performance of the marking will automatically be reduced due to the reduced transmissivity of the atmosphere as the rain is flowing, which reduces both the amount of light from the vehicle headlamps reaching the material and the amount of light returned to the driver's eyes. This, compounded with the reduction in retroreflective performance of the material itself, is represented in this result.

A significant interaction was found between Participant Age and Weather Condition, as shown in Figure 18. The effect of Participant Age and Weather Condition holds true for each group, with Dry conditions producing the highest, and Rain conditions producing the lowest distances for each age group; younger participants had higher Detection Distances in each condition. Although statistically significant, this comparison provides no additional information for the assessment of the material performance.

The interaction of marking and condition was also found to be significant. Figure 19 illustrates that each of the materials exhibited a common pattern with a reduction in the performance from Dry to Recovery conditions and then a further reduction in the Rain condition. Of interest, however, is that the paint in a rumble strip had no decrease in distance from Dry to Recovery conditions even though this was the first material tested in the Recovery lap and would have had the shortest time to recover. This indicates that the water drainage and the vertical faces on the rumble stripe provide quick recovery during the initial drying period.

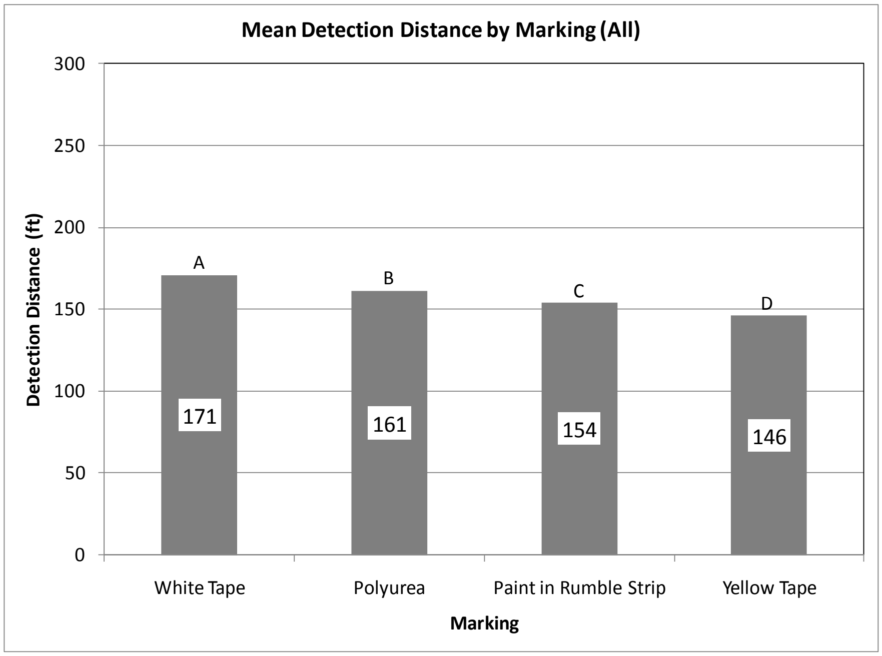

Figure 16. Mean Detection Distance by Marking (all).

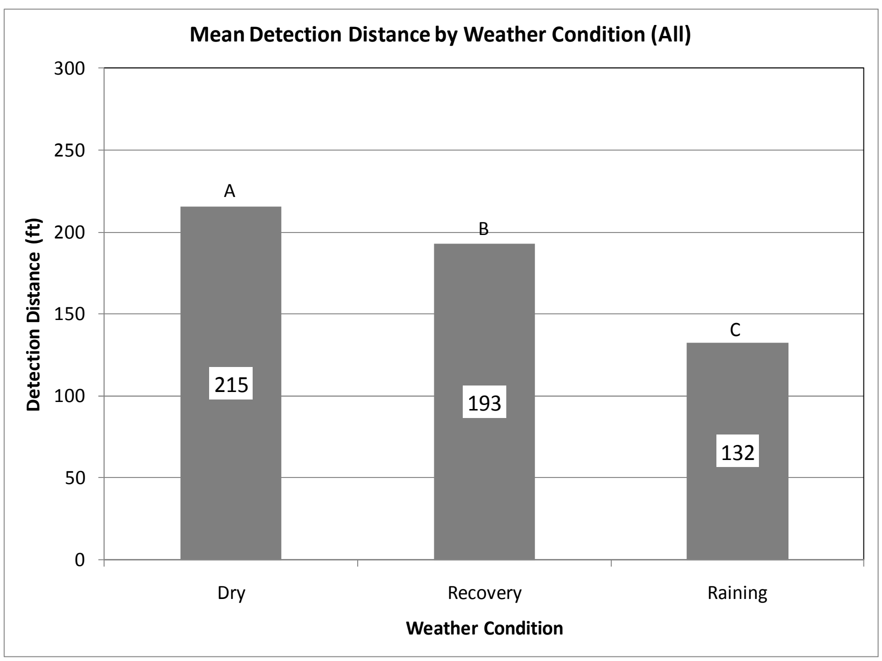

Figure 17. Mean Detection Distance by condition (all).

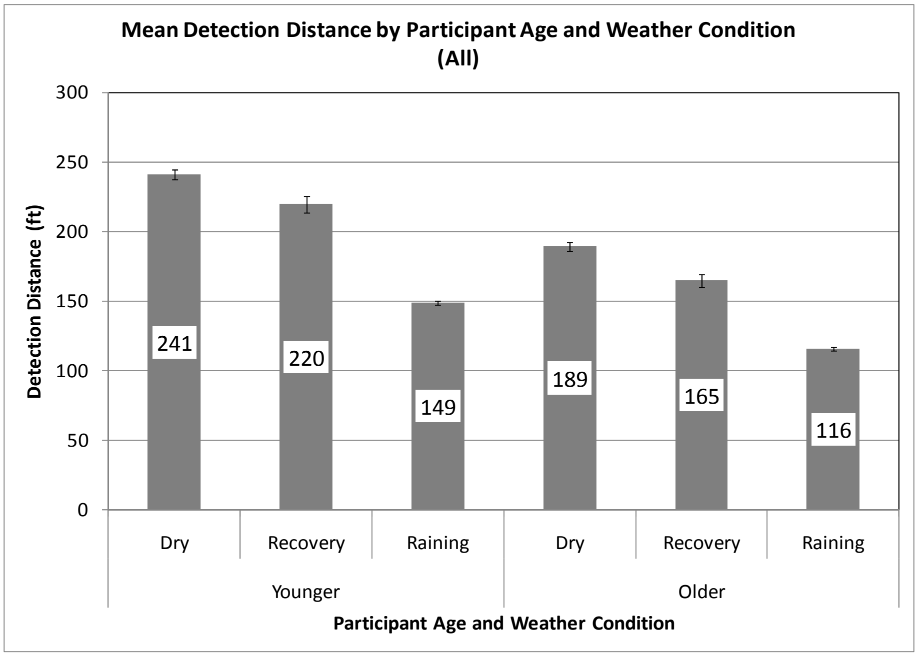

Figure 18. Mean Detection Distance by Participant Age and Weather Condition (all).

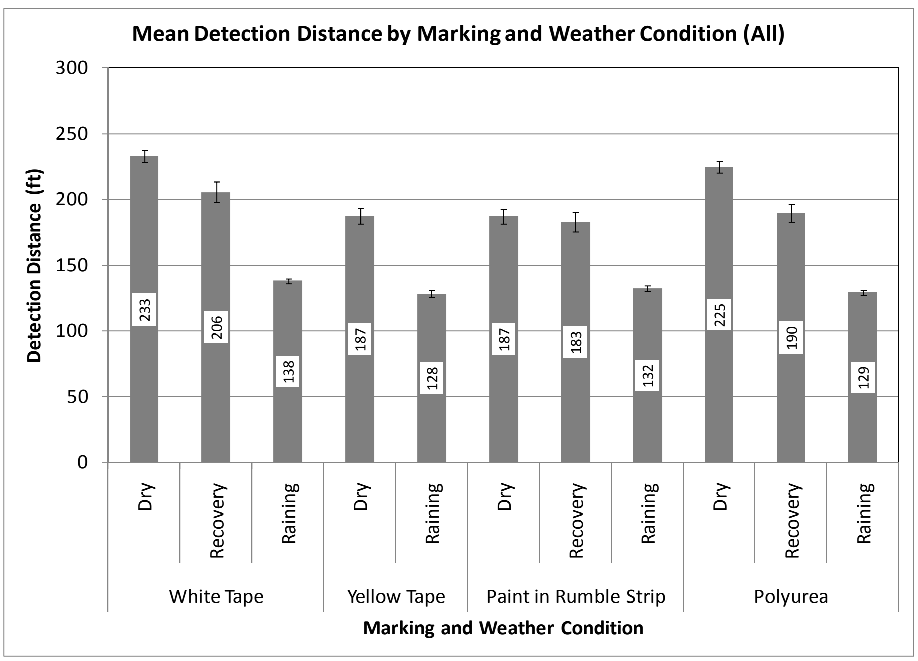

Figure 19. Mean Detection Distance by Marking and Weather Condition (all).

Rain Conditions

The analysis for the rain conditions considered the Detection Distance as a result of Participant Age and Marking Type only. The rain rate used was 0.8 in/hr, which is a 95th percentile rain event in Virginia. The results for this ANOVA are summarized in Table 4. The significant factors are denoted by an asterisk and the associated F values are shown.

Table 4. ANOVA results for Detection Distance (Raining).

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig.
Participant Age	1	484328.6635	484328.6635	10.36	0.004	*
Marking Type	3	37343.25179	12447.7506	3.42	0.0223	*
Participant Age*Marking Type	3	15751.67764	5250.55921	1.44	0.2388	
	7	537423.5929				
**p < 0.05 (significant).*						

Participant Age and the Marking condition were found to be significant. Figure 20 shows the mean Detection Distance for each age group. This is the same trend as seen in the overall analysis: younger participants were able to detect the ends of the lines at significantly longer distances.

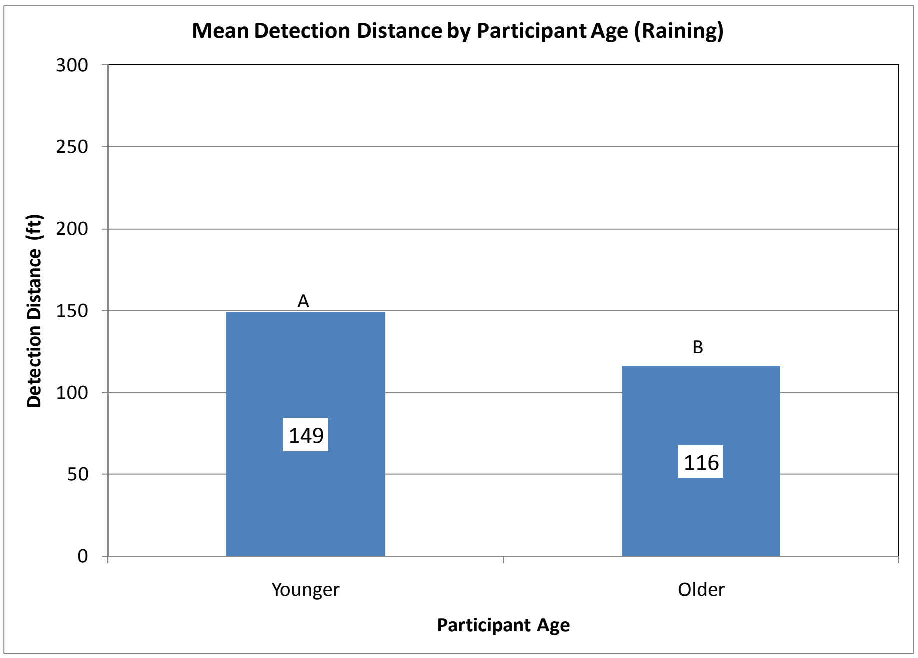

Figure 20. Mean Detection Distance by Participant Age (Raining).

As mentioned, Marking Type was also found to be significant in Rain conditions. As shown in Figure 21, the white tape had longer Detection Distances than the other three markings. It should be noted, however, that the practical difference in this comparison is very small because the mean Detection Distance for the white tape was only 6 to 10 feet longer than the other markings. At 20 mph, an increased distance of 10 feet equates to seeing the marking approximately 0.34 seconds earlier. A further Student Newman Keuls analysis shown by the letters at the top of the data columns indicate that the data all fall within a similar statistical grouping.

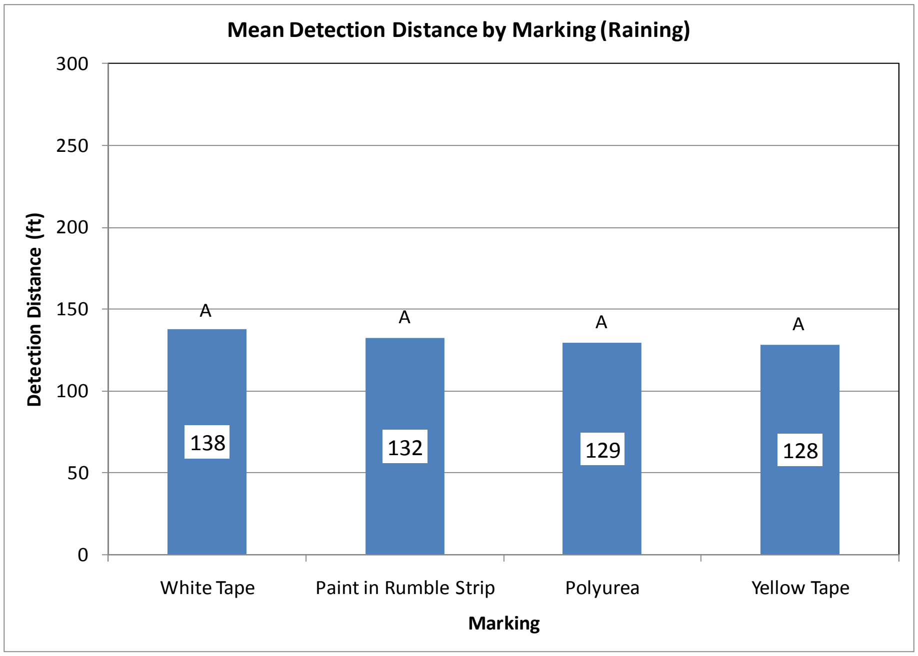

Figure 21. Mean Detection Distance by Marking (Raining).

Recovery Conditions

The second condition analysis was for Detection Distance in Recovery conditions only. The factors considered in these results were those of Participant Age and Marking. The results for Detection Distance from this ANOVA are summarized in Table 5. The significant factors are denoted by an asterisk and the associated F values are shown.

Table 5. ANOVA results for Detection Distance (Recovery).

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig.
Participant Age	1	199827.1688	199827.1688	14.55	0.0009	*
Marking Type	2	27245.61628	13622.80814	5.69	0.0064	*
Participant Age*Marking Type	2	1212.94553	606.47277	0.25	0.7774	
	5	228285.7306				
$p < 0.05$ (significant).						

Participant Age was found to be a significant factor for detection distance. Figure 22 shows the mean detection distance for each age group. This is again the same trend as seen in the other analyses. Younger participants were able to detect the ends of the lines at significantly longer distances.

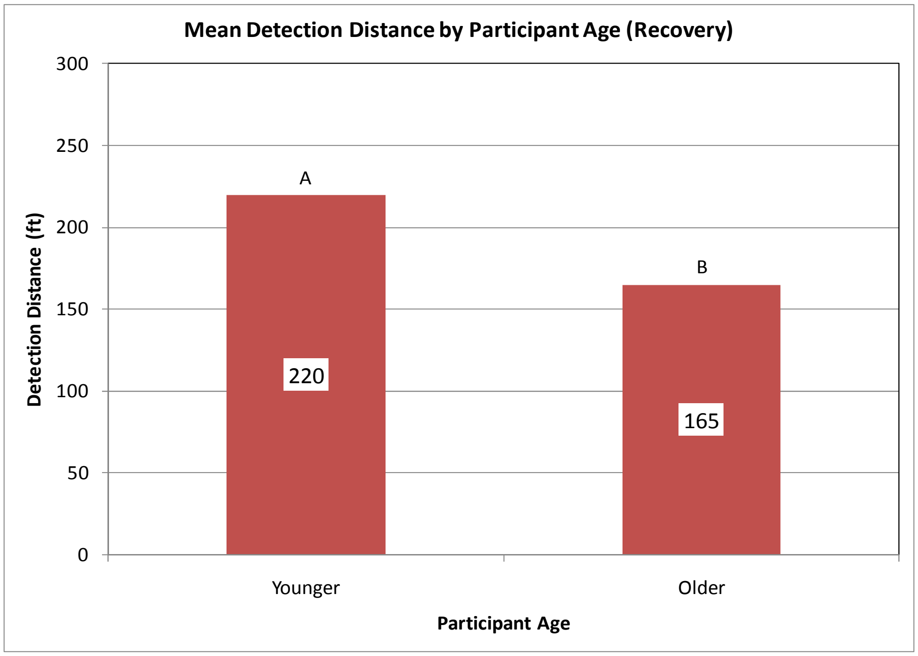

Figure 22. Mean Detection Distance by Participant Age (Recovery).

Marking was also found to be significant, as shown in Figure 23. As shown, the white tape had detection distances that were significantly higher than those for the polyurea and paint in a rumble strip.

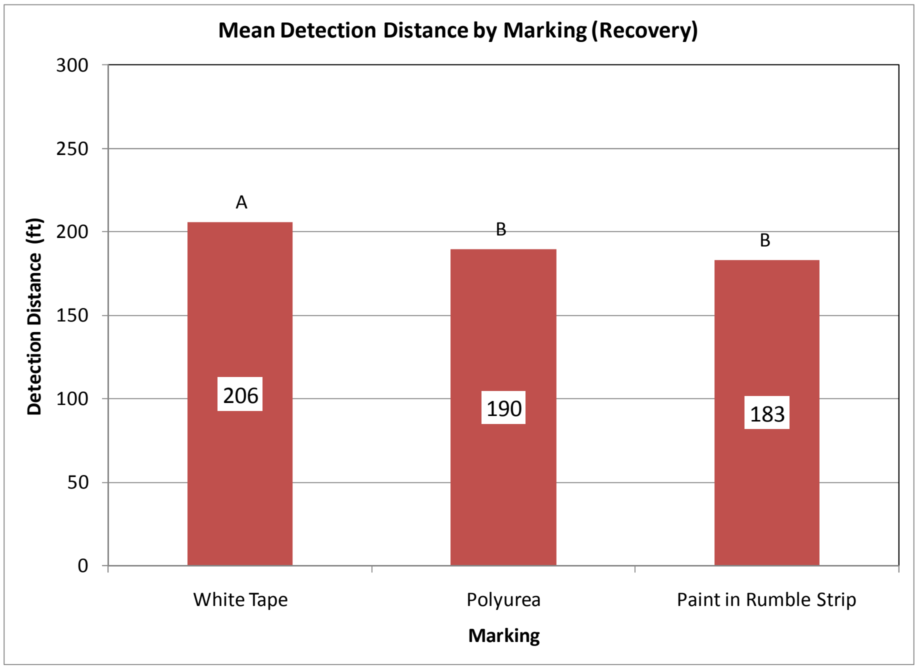

Figure 23. Mean Detection Distance by Marking (Recovery).

It is noteworthy in this comparison, however, that the paint in a rumble strip had a significantly shorter period to recover than did the other materials. During the rain shutoff, the participants were allowed to observe the rumble stripe much earlier than the other materials due to the configuration of the materials at the test facility. This recovery back to almost the same performance over a shorter period of time reflects the possible benefit of using the rumble stripe technique.

Dry Conditions

The final condition analysis performed was of detection distance in Dry conditions only. The results for Detection Distance from this ANOVA are summarized in Table 6. The significant factors are denoted by an asterisk and the associated F values are shown.

Table 6. ANOVA results for Detection Distance (Dry).

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig.
Participant Age	1	384815.6503	384815.6503	2.84	0.1226	
Marking Type	3	316106.7757	105368.9252	24.53	<.0001	*
Participant Age*Marking Type	3	10430.7916	3476.9305	0.81	0.4986	
	7	711353.2176				
**p < 0.05 (significant).*						

In this analysis, only the Marking Type was found to be significant and is shown in Figure 24. As seen in the figure, the white tape and the polyurea had detection distances that were significantly longer than the ones recorded for the paint in the rumble strip and the yellow tape.

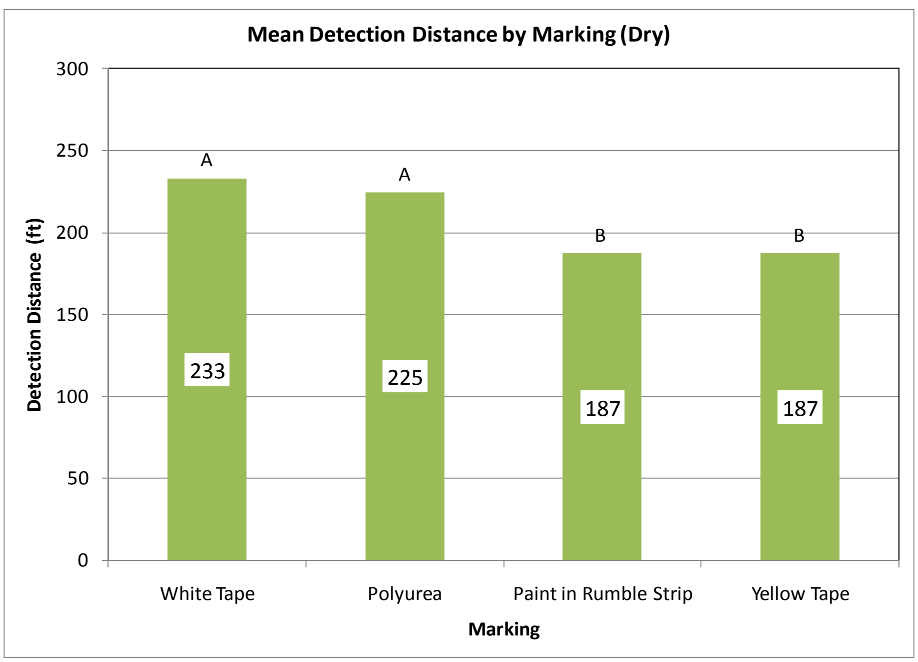

Figure 24. Mean Detection Distance by Marking (Dry).

Additional Analyses

Two additional analyses were undertaken to investigate the impact of the end point and the seasonal issue on the experimental results. The first considered was the end point.

End Point Analysis

To consider the impact of the end point, additional analysis on the rain performance data was performed. The factors considered in these results were those of Participant Age, Marking, End Point, and Weather Condition. In this analysis, ANOVA calculations were performed for each combination of factors. This ANOVA was a 2 (Participant Age) x 2 (End Point) x 4 (Marking) mixed-factors design. For this End Point analysis, start and stop were used to indicate whether the detection distance represented the start of a line or the end of a line. The results for Detection Distance from this ANOVA are summarized in Table 7. The significant factors are denoted by an asterisk and the associated F values are shown.

Table 7. ANOVA results for Rain conditions including End Point type.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig.
Participant Age	1	489484.4111	489484.4111	10.65	0.0036	*
End Point	1	19020.61929	19020.61929	2.96	0.0992	
Participant Age*End Point	1	8839.19362	8839.19362	1.38	0.2532	
Marking Type	3	44200.92326	14733.64109	3.98	0.0114	*
Age*Marking Type	3	19658.05427	6552.68476	1.77	0.1614	
End Point*Marking Type	3	133466.5568	44488.8523	19.99	<.0001	*
Participant Age*End Point*Marking Type	3	27226.1222	9075.3741	4.08	0.0102	*
$*p < 0.05$ (significant).						

In this analysis, Participant Age and Marking Type were found to be significant as in the previous analysis; however, the interaction of the end point and the marking as well as the three-way interaction of the End Point, Marking, and Participant Age were also significant.

Figure 25 shows the significant interaction of End Point and Marking. For the white tape and the polyurea, detection distances were significantly higher for start points. The yellow tape and the paint in a rumble strip, however, had significantly lower detection distances for start points. One thing to consider here is that the 3M white tape and the polyurea were installed on a main portion of the Smart Road, and the yellow tape and the paint in a rumble strip were installed on the auxiliary road. It is possible that some characteristic of the roadway itself is having an influence. For example, entering the auxiliary road required making two sharp turns. Performing this maneuver and then bringing the vehicle up to the desired speed may have distracted participants, causing lower than normal detections for the start points of the yellow tape and high build paint.

The significant three-way interaction of Participant Age, End Point, and Marking is shown in Figure 26. The effect of End Point and Marking is seen to hold true across age groups. However, one point in particular stands out. The detection distance for the white tape at a start point is considerably higher for younger participants than any other condition. It is unclear why this point impacted the data significantly; however, it seems to be the cause of the interaction.

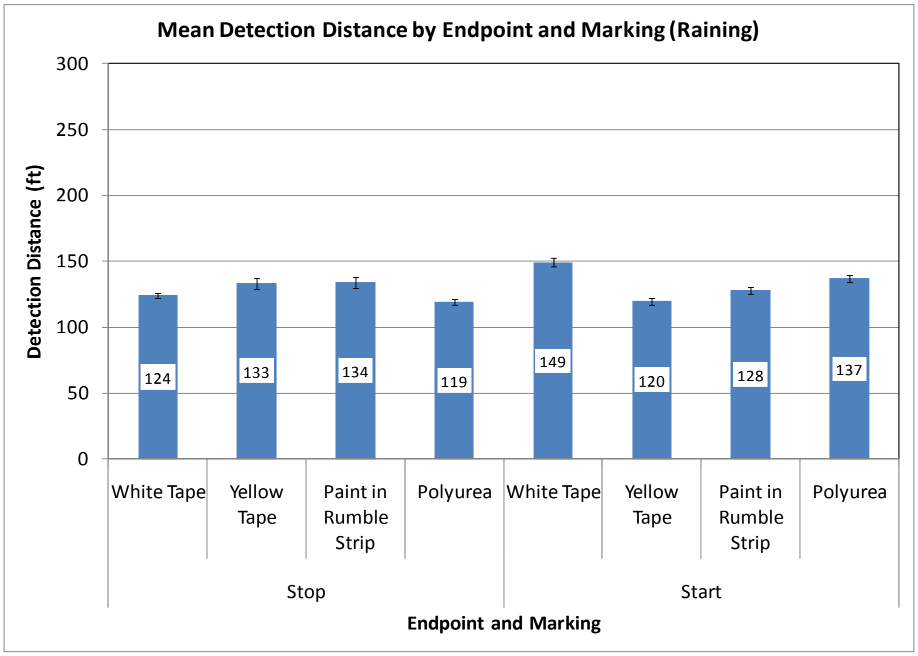

Figure 25. Mean Detection Distance by End Point and Marking (Raining).

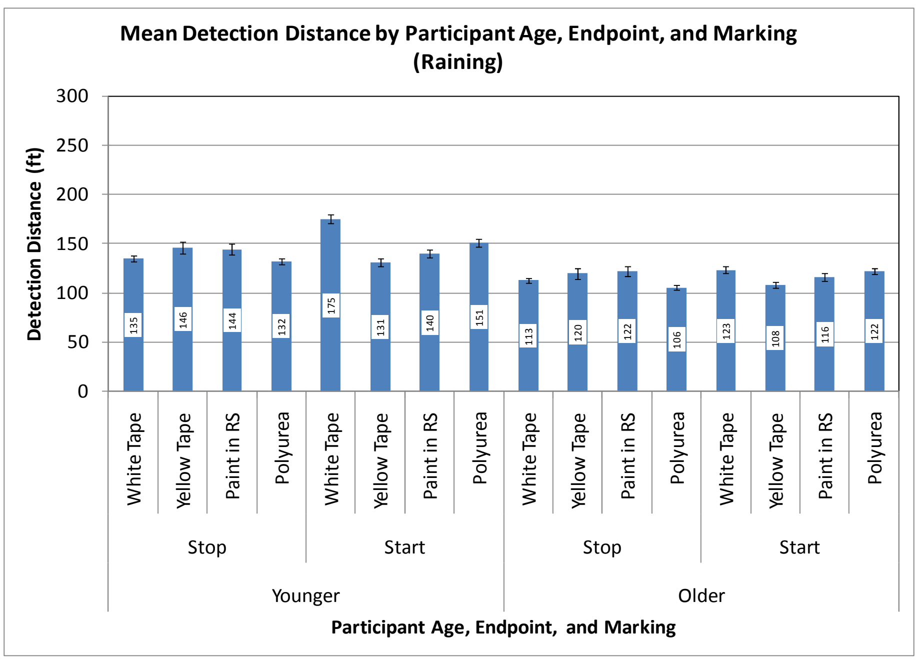

Figure 26. Mean Detection Distance by Participant Age, End Point, and Marking (Raining).

In general, from this analysis, it does not appear that the type of end point influenced the results.

Seasonal Analysis

As mentioned, due to the severity of the winter season at the test location, only half of the participants could be tested in the fall and the other half were tested during the spring. During this time, to preserve the marking condition, snow removal equipment was not allowed on the test area. This participant split existed for the Rain conditions only.

In order to assess this impact, an additional analysis was undertaken to investigate these effects. An ANOVA for the rain results was performed with Season, Participant Age, and Marking Type as the Main Factors. This ANOVA was a 2 (Participant Age) x 2 (Season) x 4 (Marking) mixed-factors design. The results for Detection Distance from this ANOVA are summarized in Table 8. The significant factors are denoted by an asterisk and the associated F values are shown.

Table 8. ANOVA results for Rain Conditions including Season.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig.
Age	1	484328.6635	484328.6635	10.89	0.0036	*
Season	1	4823.2796	4823.2796	0.11	0.7453	
Age*Season	1	142828.8173	142828.8173	3.21	0.0883	
Marking	3	37343.25179	12447.7506	4.98	0.0038	*
Age*Marking	3	15751.67764	5250.55921	2.1	0.1096	
Season*Marking	3	82075.176	27358.392	10.95	<.0001	*
Age*Season*Marking	3	7443.88526	2481.29509	0.99	0.4024	
	15	774594.7511				
**p < 0.05 (significant).*						

In this analysis, Participant Age and Marking Type were found to be significant as in the previous analysis. The Season was not found to be significant; however, the interaction of the Season and the Marking Type was found to be significant. This interaction is shown in Figure 27.

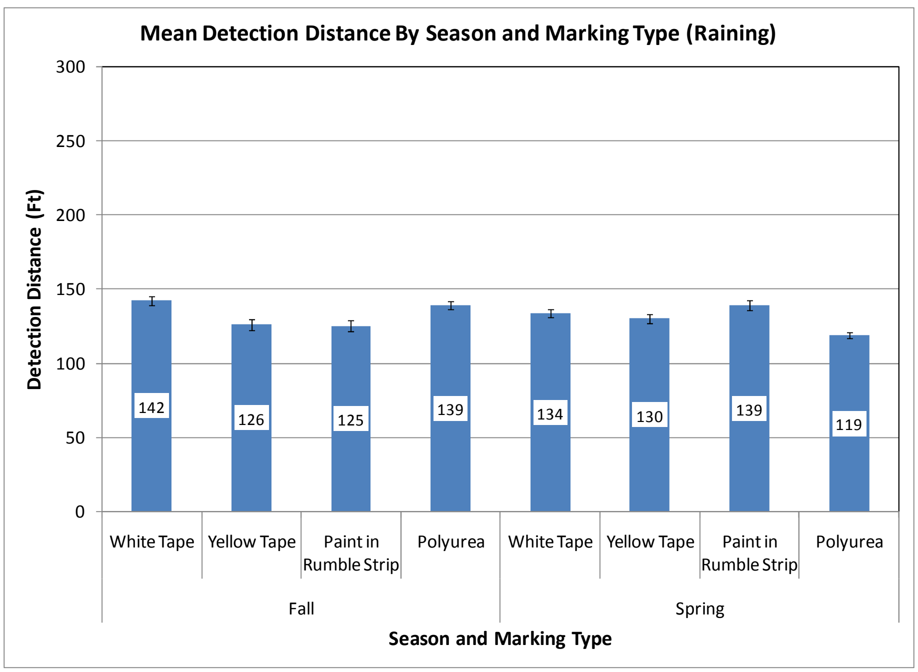

Figure 27. Mean Detection Distance by Season and Marking (Raining).

Here it appears that the markings on the main portion of the Smart Road (white tape and polyurea) were more impacted than the markings on the auxiliary road (yellow tape and paint in a rumble strip). During the winter season, the main Smart Road was plowed without touching the markings; however, snow was piled on the materials. The auxiliary road was not plowed at all. This difference may result in the differences shown here. The material showing the most impact is the polyurea with an approximately 20-ft change in detection distance. In light of the close values in the rain results (6-10 ft difference between all of the materials), this seasonal change would not have made a dramatic or practical impact on the results.

Retroreflectivity

Retroreflectivity is the measurement of how much light is returned to a viewer's eyes when looking at an object; in this case, a pavement marking. Retroreflectivity measurements were taken at three places for each marking segment: the beginning, middle, and end of the line. These were averaged together to create an overall average retroreflectivity for each marking segment.

Readings were recorded for four conditions, which include Dry, the Bucket Test, 1 in/hr rain, and 2 in/hr rain. The pavement markings were installed in May 2009, and retroreflectivity measurements were taken in August 2009 and April 2010. This allows for the consideration of the changes in the material over time. The data were analyzed in terms of months since installation, where the August readings were in the third month and the April readings were in the eleventh month.

Figure 28 presents the mean retroreflectivity for each marking segment for each of the measurement methods (both sets of monthly recordings were averaged). As seen, all of the

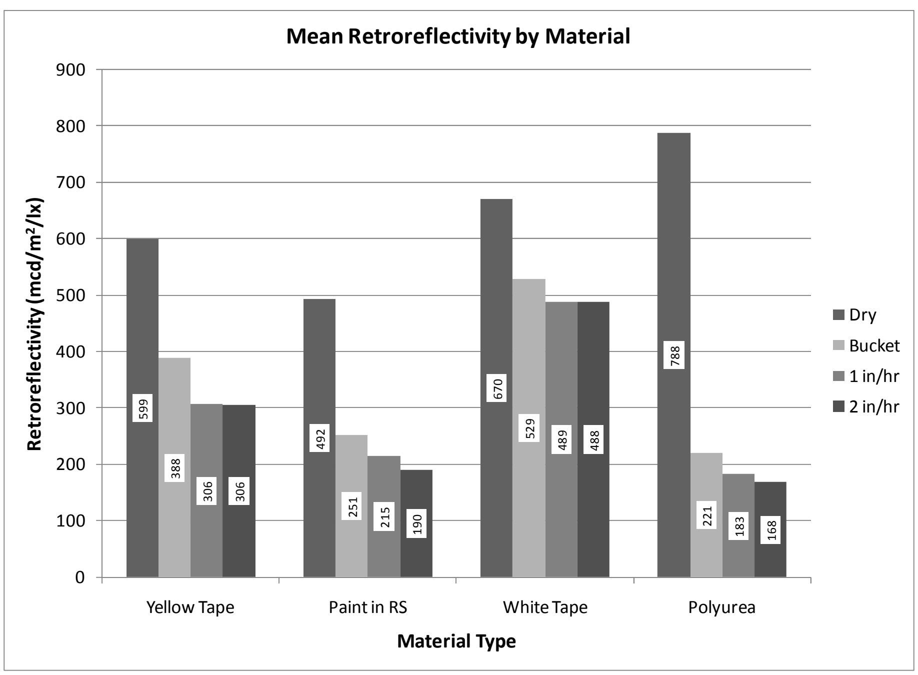

Figure 28. Mean Retroreflectivity in all test methods.

markings had reduced retroreflectivity in the wet test conditions. It is noteworthy that the 1 in/hr box method and the 2 in/hr box method typically showed a similar value with the Bucket Test having a high result. The drop in the retroreflectivity for the polyurea material from the dry to the wet conditions also seems much higher than expected in comparison to the other materials.

The change in the retroreflectivity measurements from the third month after installation to the eleventh month after installation is shown in Figure 29. The most obvious change is the measurement increase in the paint in a rumble strip. This is both highly unexpected and highly unlikely. It should be remembered that the Ennis material is placed on a rumble strip and this study used a method of measurement that differed from the standard established by ASTM International. According to the ASTM International E1710-05 designation, the correct method is to average several measurements taken over one cycle of the rumble strip. However, for this study, measurements were taken at the point along the cycle that resulted in the highest values and believed to be most highly related to the visibility.

The lack of change in the yellow tape material is also interesting. Overall, the retroreflectivity of the materials on the Smart Road may have been more influenced than those on the auxiliary road. The overall change in the material performance is being considered in the other (parallel) project on the durability of the marking materials. More information should be available at the conclusion of that project.

The final consideration in the retroreflectivity measurements was that of direction (Figure 30). The white tape and the polyurea were installed on the Smart Road. As the Road has a 6% slope, the materials were able to be viewed as the roadway was going downhill and as the roadway was going uphill. These two conditions represent a different drainage pattern for the marking and influenced the retroreflectivity measurements. In general, the uphill measurements

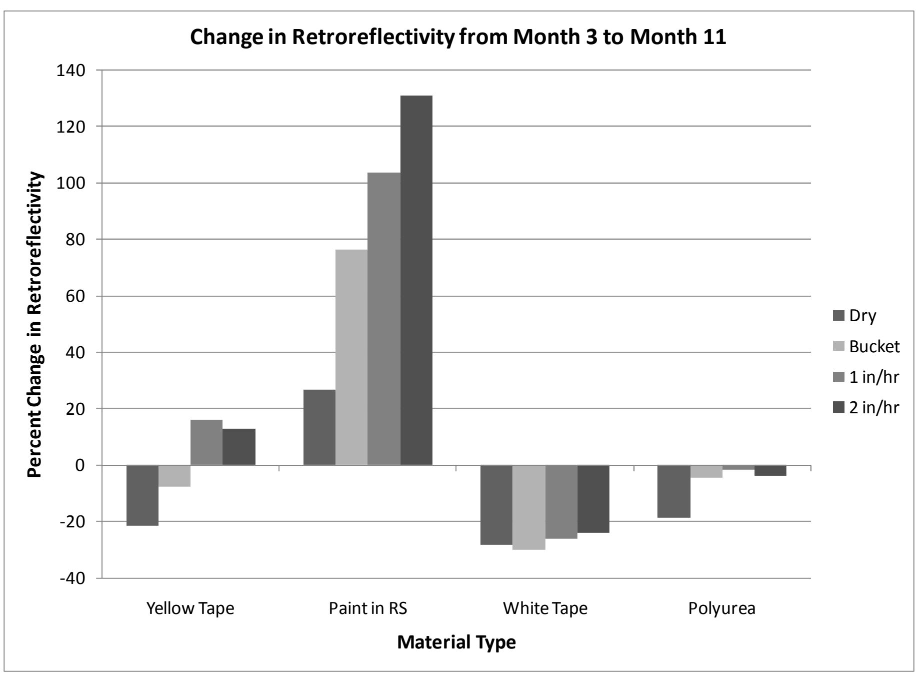

Figure 29. Change in Retroreflectivity from Month 3 to Month 11.

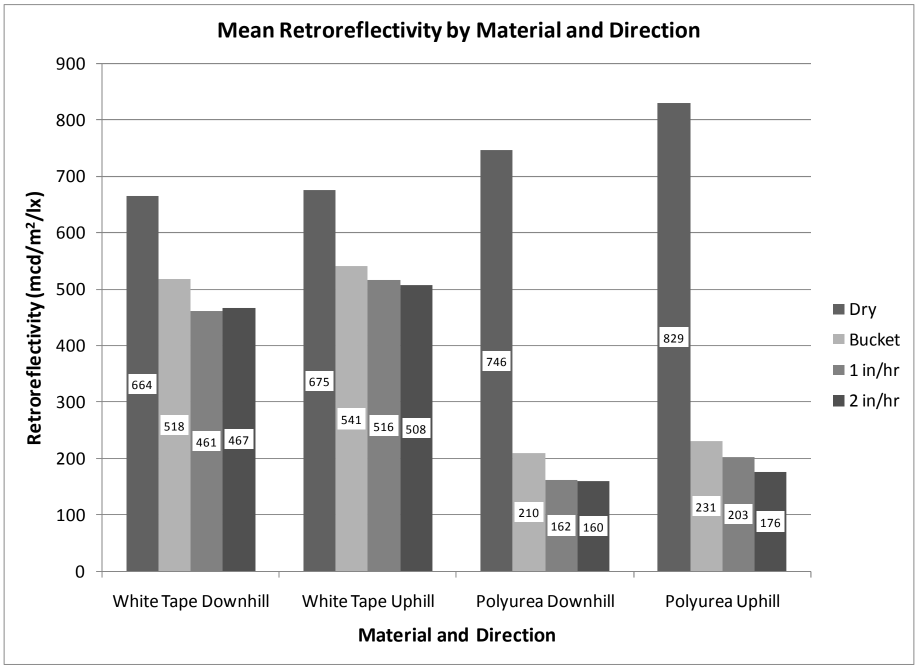

Figure 30. Mean Retroreflectivity in 2 in/hr rain.

were higher than those while looking downhill. For the wet measurements methods, water would be draining towards the instrument and may have resulted in an increase in the results. It is unclear why the dry measurements would change with direction but this may be a result of the material installation. Here the high build paint is manufactured as it is installed, whereas the tape is manufactured in a facility and installed later. It is expected that the tape would have a much higher consistency than the other materials.

Summary

In general, the results show that the materials performed similarly in the wet night conditions. Although each of the materials had significant reduction from the dry to the wet conditions, they were all within 10 ft of detection distance when compared. However, the retroreflectivity measurements show a greater variation than does the detection distance. The influence of driver age was predictable and followed the expected trend. The final note is that the rumble stripe configuration of the marking materials seemed to show better performance in the Recovery condition than did the other tested materials.

DISCUSSION

The results from this experiment can be used to develop a required retroreflectivity value to establish proper visibility distances for pavement markings. The comparison of these measurement results to those of the previous investigations and the correlation of the retroreflectivity to performance should be considered. Also, the applicability of the retroreflective measurements to both yellow and white marking types should be considered.

Comparisons to Previous Studies

A similar experimental method was used in the previous Wet Visibility work and a comparison of those results to the ones in this experiment is an interesting validation of this experiment. The materials used in the previous investigation were standard white latex paint with standard-sized glass beads, standard latex paint with large-sized glass beads, profiled thermoplastic, and an older generation wet retroreflective tape. The rain conditions in the previous studies were the same as those used in this study; however, the experimental vehicles were different. This study used two match sedans where the previous study included a sedan and a large truck. This comparison considers the sedan data from the previous experiment to the current vehicle data.

The comparison of these materials is shown in Figure 31 for wet conditions and in Figure 32 for dry conditions (note that Beads refers to the Large Bead Product and Paint refers to the Standard Latex Paint product).

This comparison shows that, in the wet conditions, the technologies studied in this investigation outperformed those in the previous study, with the exception of the tape. For the dry conditions, all of the materials are within the same region of performance. The tape used in this experiment was of a different structure as compared to the manufacturer tape from the earlier work, which is now discontinued.

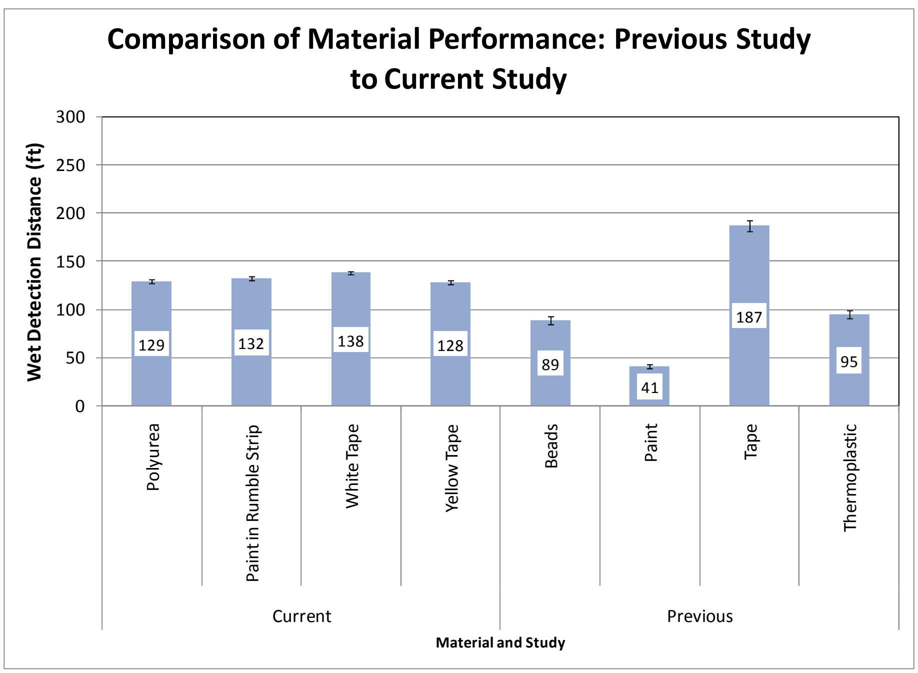

Figure 31. Detection Distance comparison to previous experiments in Rain conditions.

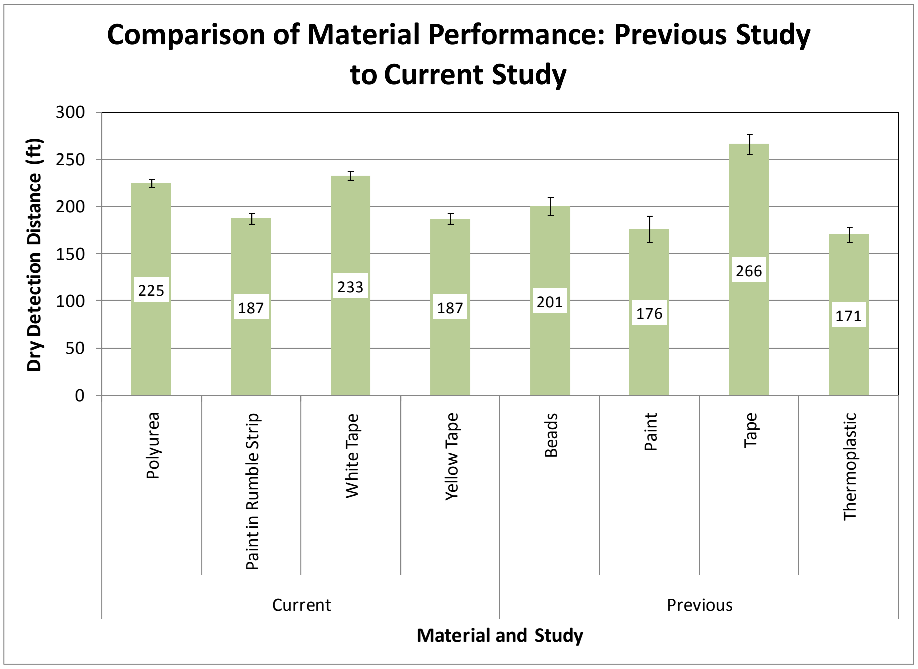

Figure 32. Detection Distance comparison to previous experiments in Dry conditions.

Correlation of Retroreflectivity and Detection Distance

To be a valuable indicator of material performance, the measured retroreflectivity must be related to the visual performance determined here. An initial correlation matrix of Pearson correlation coefficients between the detection distance and the retroreflectivity has been developed and is shown in Table 9.

Table 9 shows that for the dry detection distance, the correlation to the dry retroreflectivity is fairly strong. As expected, the wet detection distances are not correlated to the dry measurements but are more strongly correlated to the wet-based measurements. For the wet conditions, the strongest correlation is the 1 in/hr rain box test. The best correlations are for the Recovery data. Here, the strongest correlations are to the Bucket method, which is the test type most similar to a Recovery activity. However, the correlation values are very high for each condition; there is likely no impact if a different test methodology was used in the specification. It is noteworthy, however, that there are very limited data for this comparison in that only four material types were tested.

Table 9. Correlation Results for the Retroreflectivity Measurements and the Detection Performance for the Tested Materials (N = 4).

		Test Method			
		Dry	**Bucket**	**1 in /hr**	**2 in /hr**
Condition	Dry	0.88079	0.41138	0.4437	0.43902
	Recovery	0.42353	0.96603	0.95136	0.96314
	Wet	0.09009	0.64829	0.72948	0.6871

The previous studies (Gibbons et. al, 2004, Gibbons, 2006) showed that the detection distance and the retroreflectivity were related through a linear –log (base 10) equation developed as:

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

The coefficients for a and b were found to be 57.33 and -10.2, respectively, for a sedan similar to what was used in this investigation. This model, however, was based on a camera method to calculate the retroreflectivity, whereas the research present here uses typical retroreflectivity instruments. This model was redeveloped with the new instrument retroreflectivity values. For the Dry measurements, the model was based on the Dry retroreflectivity results; for the Recovery measurements, the model was based on the Bucket Test method; and for the wet conditions, the model was based on the 1 in/hr rain box method as this was the method with the highest correlation. The results are shown in Table 10. It is important to note here that the models are based on a limited number of data points (N = 4).

Table 10. Regression results for logarithmic model of Detection Distance and Retroreflectivity based on instrument measurements (N = 4).

Condition	Measurement Type	a	b	r^2
Dry	Dry	324.00	-695.21	0.7980
Recovery	Bucket	52.42	63.39	0.9400
Wet	1 inch per hour	13.74	98.58	0.4215

The model seems to show a good correlation with the limited data provided. The concern on the fit for the dry measurements is that the intercept indicates that the distance will be negative at some point while the retroreflectivity is present. An additional model was developed for these data with no intercept values to constrict the model more closely at low levels. The coefficients for this model are shown in Table 11.

Table 11. Regression results for logarithmic model of Detection Distance and Retroreflectivity with no intercept (N = 4).

Condition	Measurement Type	a	r^2
Dry	Dry	74.73	0.33
Recovery	Bucket	77.95	0.72
Wet	1 inch per hour	54.11	0.32

The data and the models are shown in Figure 33. Here the solid lines represent the models with no intercepts and the dashed lines represent those with an intercept. While the r^2 correlations are lower, it is believed that the models with no intercept likely represent reality for this limited dataset more clearly than the models with the intercepts as this will force the results to have zero visibility distance for zero reflectivity.

The complete model for the non-intercept version is shown in Figure 34.

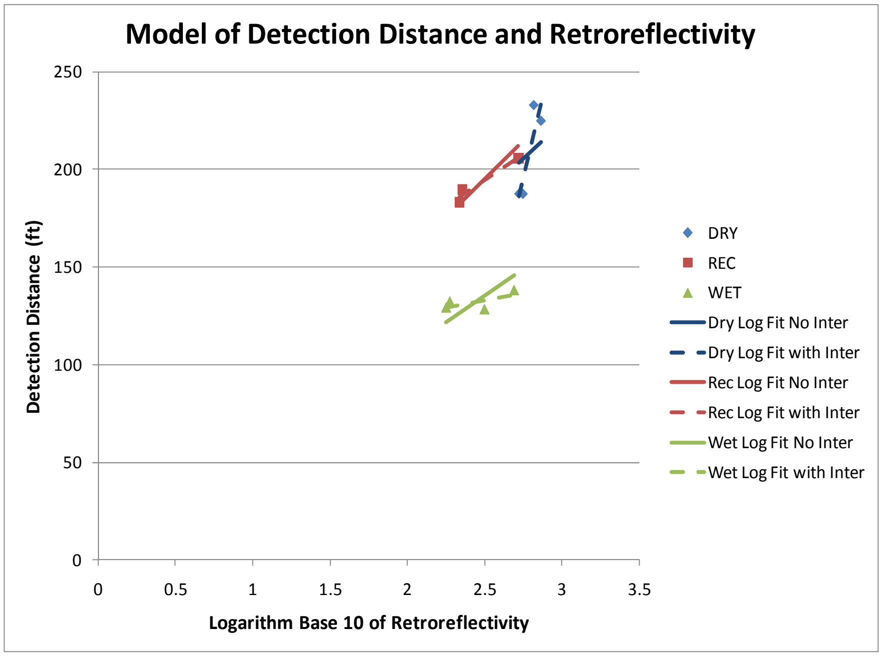

Figure 33. Logarithmic model of the Detection Distance and Retroreflectivity.

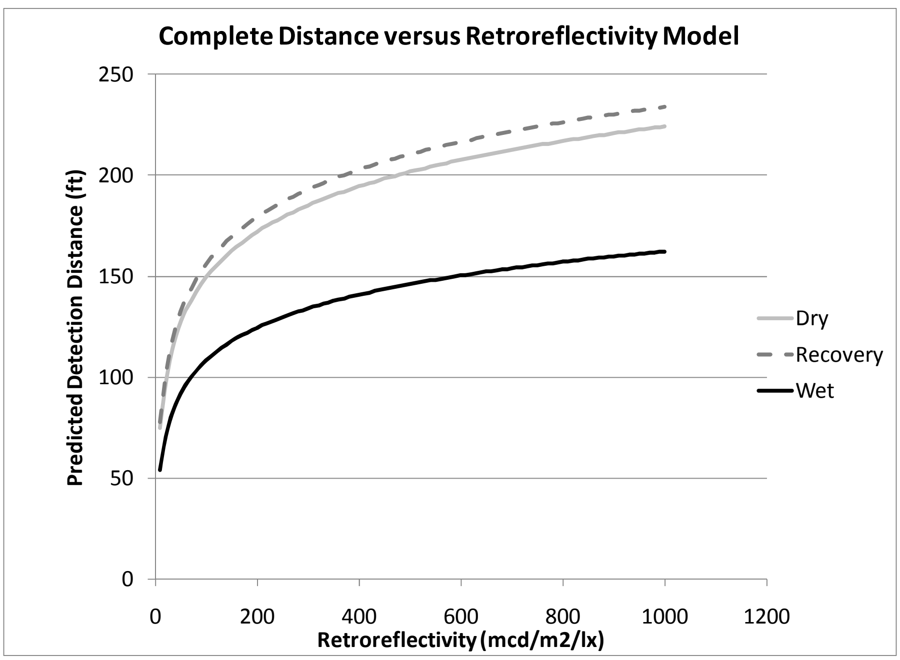

Figure 34. Full Retroreflectivity model for each condition.

Based on this model, it appears that the retroreflectivity begins to provide diminishing returns at levels above 200 – 250 mcd/m^2/lx for the dry condition and 150 mcd/m^2/lx for the wet condition. This is a similar value to that found in the previous Wet Night Visibility Study. This means that the amount of detection distance gained for a unit increase in retroreflectivity becomes less and less as retroreflectivity increases beyond this range.

The analysis of the luminance camera images supports this model. Figure 35 shows the mean detection distance by the calculated retroreflectivity for the raining conditions, along with the associated model created from these data. For these data, the model was found to be:

$$Detection\ Distance = 57.555 \cdot \log(Retroreflectivity) + 64.607$$

While the parameters of this function are different from that obtained using the measured retroreflectivity, this function still supports the idea of diminishing returns at levels above 150 mcd/m^2/lx. The deviation in this function is likely due to the variability inherent in calculating the retroreflectivity from realistic driving scenarios, and predicted levels of illuminance.

Using the model developed in the previous investigation, a recommendation of 200 mcd/m^2/lx was developed for adequate wet retroreflectivity in night conditions. This value was established based on a 2- or 3-second sight distance for a driver. From the results of this study, the retroreflectivity relationship has been more clearly defined and a value of 150 mcd/m^2/lx has been developed. Using the lower value of 150 mcd/m^2/lx results in a difference of 10 ft of detection versus the earlier recommended value of 200 mcd/m^2/lx. Using each of the developed models, the speed and required retroreflectivity can be developed. These data, as well as the recommended level and material performance, are shown in Figure 36 and Figure 37 for dry and wet conditions, respectively.

These figures show that the limit of 150 mcd/m^2/lx provides adequate visibility for 55 mph in dry conditions, and 40 mph in wet conditions based on a 2-second visibility distance.

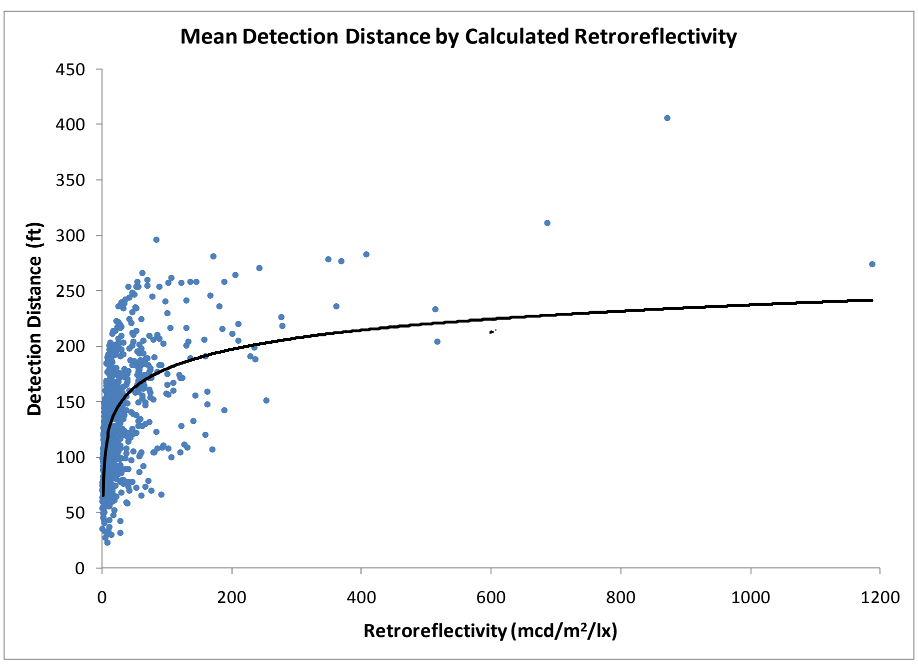

Figure 35. Mean detection distance by calculated retroreflectivity.

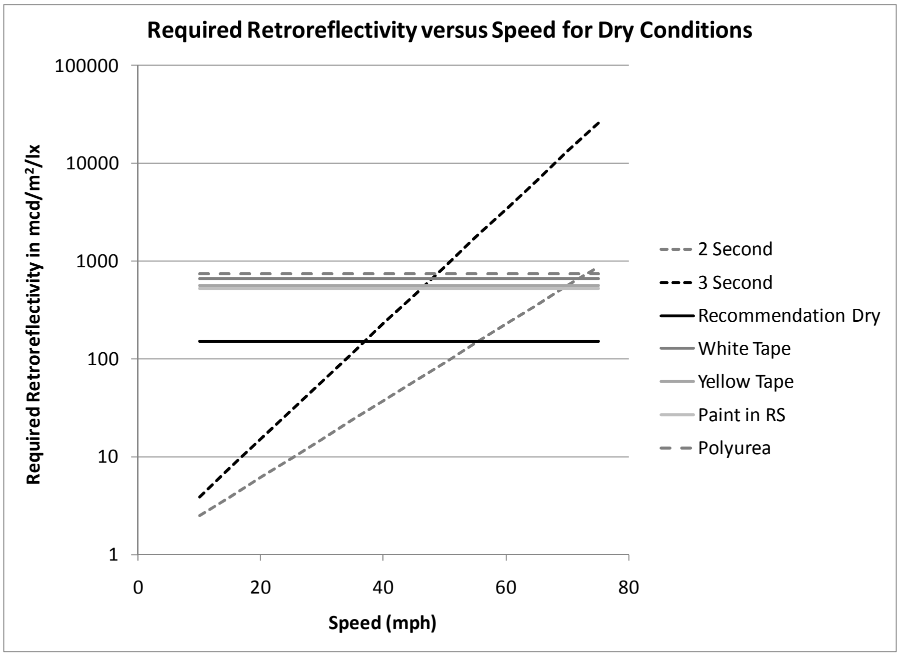

Figure 36. Required Retroreflectivity versus speed and material performance for Dry conditions.

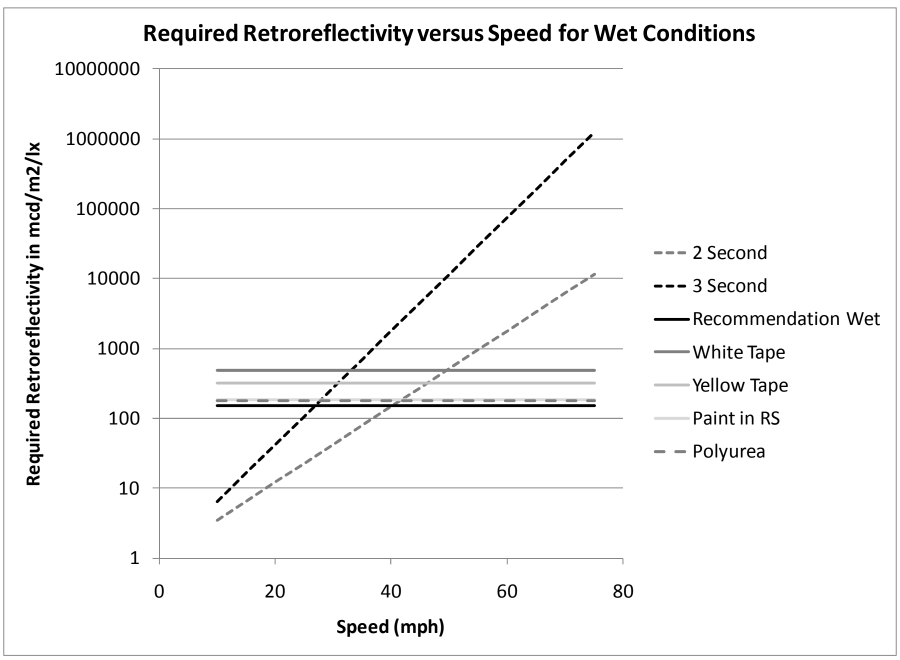

Figure 37. Required Retroreflectivity versus speed and material performance for Wet conditions.

A lookup table for the required retroreflectivity by speed is shown in Table 12. These values are based on dry retroreflectivity measurements for the Dry condition and 1 in/hr rain box measurements for the Wet conditions. It is important to note that the required retroreflectivity level in Wet Conditions is greater than the results for all of the measured materials in this study for all speeds over 40 mph. This is similar to the results from the earlier experiments.

Table 12. Required Retroreflectivity by Speed for Dry and Wet Night conditions.

	2 Second		3 Second	
Speed	**Dry**	**Wet**	**Dry**	**Wet**
10	2	3	4	7
15	4	7	8	17
20	6	12	15	42
25	10	23	30	108
30	15	42	58	275
35	24	79	115	702
40	37	147	226	1789
45	58	275	446	4563
50	92	514	879	11638
55	144	959	1731	29679
60	226	1789	3409	75690
65	356	3340	6714	193031
70	559	6235	13223	492282
75	879	11638	26045	1255453

Yellow and White Comparisons

Typical specifications for the retroreflectivity of pavement markings have a required retroreflectivity value for the white marking color and a required value of 50% of the white value for the yellow marking color. This specification difference has been developed historically, based on the performance capabilities of the marking materials themselves. Traditional marking technologies have only been able to produce a retroreflectivity in a yellow marking that is about 50% of the white. As most specifications are material-based and not visibility-based, this retroreflectivity specification has been carried forward.

In this experiment, the yellow tape product and the white tape product are capable of being compared in the same conditions. These two tape products have matching construction and would be expected to perform similarly. The comparison of the retroreflectivity and the detection distance is shown in Figure 38.

In this comparison, the performance of the yellow marking is less than that of the white marking for both the Rain and Dry conditions, and follows a similar trend as the retroreflectivity. Halving the required specification for the yellow would further reduce the performance of the material in the Rain conditions. From this comparison, it is not likely that a yellow material specification of 50% of the white value would be adequate for visibility.

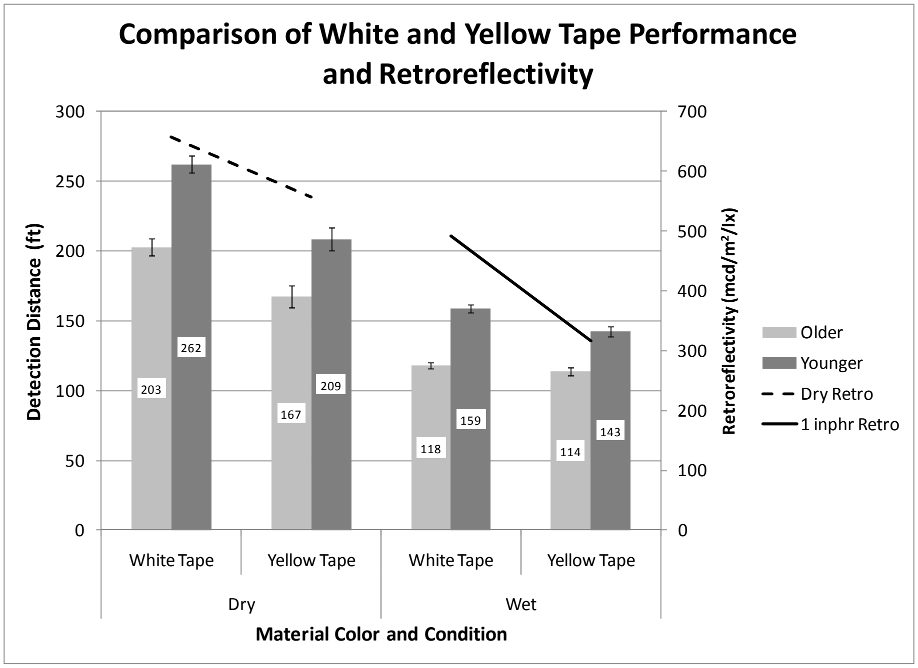

Figure 38. Detection Distance and Retroreflectivity for the yellow and white markings.

Compliant Materials

All of the materials in this investigation met the proposed 150 mcd/m^2/lx criteria. However, it is noteworthy that the specifications are based on diminishing returns and that the speeds attainable are only 40 mph in wet conditions and 55 mph in dry. Higher performance levels of retroreflectivity will provide an additional visibility distance.

CONCLUSIONS

- *The materials developed over recent years show an improved performance over those tested previously except for the old style tape material.*

- *The log-linear relationship found previously is functional for the data provided. Two models were developed. The model with no intercept provides a more constrictive boundary at low levels of retroreflectivity.*

- *A retroreflectivity value above 250 mcd/m^2/lx provides limited return in terms of detection distance.*

- *A specification limit of 150 mcd/m^2/lx will provide adequate visibility for 55 mph in dry conditions and 40 mph in wet conditions using standard dry retroreflectivity measurements,* *and 1 in/hr measurements for the wet conditions. This value should be the minimum maintained over the life of the marking.*

- *The retroreflectivity specification for a white and a yellow material should be equal.*

- *The rumble stripe showed a significant recovery time improvement over the other tested materials.*

RECOMMENDATION

Based on the visibility needs of drivers, VDOT should establish a 150 mcd/m^2/lx minimum for retroreflective pavement marking materials based on dry measurements and 1 in/hr rain box measurements.

Durability of the marking material may also impact the long-range performance of the materials. This is being considered in the parallel study being performed at VTTI. This project is monitoring the retroreflectivity of markings installed on a public highway over a 20-month period and will be complete in 2011. The recommended specification may be amended upon consideration of these results.

BENEFITS AND IMPLEMENTATION PROSPECTS

Implementation of the recommendation should provide the following benefits:

- greater visibility of pavement markings for drivers in wet night conditions

- improved visibility of roadways through the improvement of lane and roadway delineation

- improved safety through increased wet night visibility conditions by a reduction in lane departure and run-off-road crashes.

However, the following may also occur:

- possible decrease in the life of a marking in order to maintain the minimum specification

- possible increase in the rate of reinstallation in order to maintain the minimum specification.

The implementation prospects are high. VDOT's Traffic Engineering Division is preparing a pavement marking policy. It is anticipated that the recommendations and results of this study and the related study on the durability of wet night visible pavement markings will be incorporated in this policy. There are several challenges in adopting a policy on pavement markings that require a minimum level of performance. A few of these are described here. First, there is some question as to whether yellow markings can achieve the minimum level recommended. The pavement marking industry may view this as a target to achieve. The minimum level is for 40 mph; this does not address the actual value needed for higher speeds, even for dry conditions. The pavement marking policy will include the use of raised pavement markers especially for highways with speed limits above 60 mph. Therefore, the recommended performance specification should be integrated with the use of raised pavement markings. Second, if a performance-based specification is adopted, VDOT must have a monitoring system in place to measure the performance of the pavement markings.

ACKNOWLEDGMENTS

The authors acknowledge VCTIR for their support of this project. Special thanks to Ben Cottrell for his assistance as project manager; in addition, thanks to James Swisher and his staff in the VDOT Materials Group for their assistance in the measurements and in procuring the test materials. Thanks to the technical review panel for this project: Van Nguyen, James Swisher, Ben Cottrell, and Cathy McGhee. Thanks also to the support from the companies who provided the materials and the installation at the test facility.

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APPENDIX A

RECRUITMENT AD FOR PARTICIPANTS

VirginiaTech
TRANSPORTATION
INSTITUTE
DRIVING TRANSPORTATION WITH TECHNOLOGY

Virginia Tech Transportation Institute is recruiting participants for a nighttime driving study being conducted at VTTI and on Virginia's Smart Road.

Participants will be paid $20 per hour for approximately three hours.

Option 1: Older (65+ years old) and Younger (18-34 years old) drivers needed (or)

Option 2: Older (65+ years old) drivers needed (or)

Option 3: Younger (18-34 years old) drivers needed

Participants must have a valid driver's license.

If interested:

Call (540) XXX-XXXX

E-mail: name@vtti.vt.edu

APPENDIX B

TELEPHONE SCRIPT AND DRIVER SCREENING QUESTIONNAIRE

Eligible: Yes No

Name____Male/Female
Phone Numbers ____
Best Time to Call ____
Screener____

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. Once this questionnaire is completed, remove this cover sheet and file separately from the screening questions.

Introductory Statement:
After prospective participant calls or you call them, use the following script to guide you through the screening interview.

Hello. My name is _____ and I am a researcher at the Virginia Tech Transportation Institute in Blacksburg, VA. I am recruiting participants for two new driving studies that look at nighttime driving and will be conducted here at the Smart Road. I obtained your contact information from the VTTI internal participant database.

The two studies will be combined into 1 nighttime driving session. The purpose of the first study is to evaluate spray and splash resulting from driving on a wet road. The purpose of the second study is to evaluate pavement markings in rain conditions. If you choose to participate, you will drive a test vehicle on the Smart Road in artificial rain. An experimenter will be with you at all times while you are driving. The vehicle is equipped with cameras that allow us to collect data. The cameras, however, are very small and are placed out of the way.

This study has two parts to it. First, we will perform simple vision tests. Providing these are passed, we will move on to the second part which involves driving an instrumented vehicle on a closed test-track in artificial rain. The study takes place at night, and will take approximately 3 hours at the Transportation Institute to complete. Participants are paid $20/hr. Does this sound like something you would be interested in doing?

If they indicated that they are <u>not</u> interested:
Thank you for your time.

If they indicated that they are interested:
That's great. Would you like to hear about the second study you would also be able to participate in?

Questions

1. *Do you have a valid driver's license?* (Criterion for participation: the response must be *Yes*)
   □ Yes □ No

2. *Please note that for tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number or VT ID number to receive payment for participation in our studies. You do NOT need to provide it now, but are you willing to provide us with your social security number?*
   □ Yes □ No

3. *What is your age?* _________ (Criterion for participation: must be 18-34, or 65 and older at time of experiment)

4. *Have you had any moving violations in the past 3 years? If so, please explain each case.*
   □ Yes (Criterion for participation: the driver must not have more than two moving violations in the past three years)
   Description: ____
   □ No

5. *Do you have normal hearing and vision?* (Criterion for participation: subject must have normal hearing and vision)
   □ Yes □ No

6. *Are you able to drive an automatic transmission vehicle without assistive devices or special equipment?* (Criterion for participation: the driver must be able to drive an automatic transmission vehicle without assistive devices)
   □ Yes □ No

7. *(Females only) Are you currently pregnant?* (Criterion for participation: the response must be *No*)
   □ Yes □ No

   If "yes" politely inform the participant that due the nature of this particular study we are not able to allow pregnant women to participate. Answer any questions and thank them for their time

8. *Have you been involved in any accidents within the past 3 years? If so, please explain.* (Criterion for participation: the driver must not have caused an accident in the past 3 years.)
   □ 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________________________________

(Criterion for participation: subject 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.)

10. *Are you currently taking any medications on a regular basis? If yes, please list them.* (Criterion for participation: subject cannot currently be taking any substances that may interfere with driving ability, cause downiness, or impair motor abilities.)
    ☐ Yes ____
    ☐ No

11. *Are you eligible for employment in the United States?* (Criterion for participation: Driver must be eligible for employment in the U.S.)
    ☐ Yes ☐ No

Note to Researcher:
If a response to any of the first 12 questions does not meet its criterion, read the following:

Unfortunately you are not eligible for this particular study (explain reason). Thank you for your time. Would you like to be called for future studies?

Criteria For Participation

1. *Must hold a valid driver's license.*
2. *Must be willing to provide SSN or VT ID number for payment.*
3. *Must not have more than two moving violations in the past three years.*
4. *Must have normal (or corrected with contacts to normal) hearing and vision.*
5. *Must be able to drive an automatic transmission vehicle without assistive devices.*
6. *Must not have caused an injurious accident in the past three years.*
7. *Females cannot be pregnant.*
8. *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.*
9. *Cannot currently be taking any substances that may interfere with driving ability, cause drowsiness or impair motor abilities.*
10. *Must be eligible for employment in the U.S.*
11. *Participants must be one of two age groups: 65+ years old or 18-34 years old to fulfill age group requirements.*

Once the researcher determines that the participant is eligible for the study:
You are eligible for the study.
I would like to set up a time when you can come to VTTI and participate in this study. Would it be possible for you to come in on ____________ (day of week) *at*____*:*____ *hrs* (time)*?*

If the response is yes, go ahead and schedule the participant.

If the response is no, ask the following to the participant:
What day and time would be convenient for you?

If requested day and time is available then schedule the participant. If requested day and time is not available then suggest closer day and time slots and see if that will work for the participant.

Once the researcher has scheduled the participant, repeat the schedule day and time back to the participant.

Great! I have you scheduled for ___________ *(day) at* ___:____ hrs.
I will be calling you a day before to remind you of your schedule. If you need to cancel or reschedule, please call me at 540-XXX-XXXX.
Here are the directions to the Institute. I can also email them to you if you wish.
From I-81:
1. Take exit 118B onto US-460 W towards Christiansburg.
2. Continue on US-460 W for approximately 10 miles.
3. Take exit 5AB toward US-460-BR W/US-460-BR E. The sign for this exit will read "Smart Road Center/Control Center.
4. Stay to your right on the exit ramp until you come to a stop sign at Industrial Park Drive.

5. Turn right onto Industrial Park Dr.
6. Take an immediate right onto Transportation Research Dr.
7. Turn left onto Transportation Research Plaza.
8. Drive up to the building.

When you come to institute you may park in any open space available and walk to the main building, which is two levels tall. The experimenter will be there to greet you a few minutes before your scheduled time. If you do not see anybody, please wait and an experimenter will be with you shortly.

We ask that all subjects refrain from drinking alcohol and taking any substances that will impair their ability to drive prior to participating in our study.

Please bring reading glasses if you typically use them for filling out forms.

Do you have any questions that I can answer for you? (Answer the questions if any).

Great then I'll see you on _____________ (day) *at* ____:____ hrs *for the study. Thanks. Have a good day.*

APPENDIX C

INFORMED CONSENT FORM
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: The Refinement of Drivers' Visibility Needs During Wet-Night Conditions
Investigators: Dr. Ronald Gibbons, Chris Edwards, Brian Williams, Jason Meyer, Derek Viita

I. The Purpose of this Research/Project

Pavement markings serve several purposes. They provide guidance to drivers, and convey rules of the road. Pavement markings may also alert drivers to something ahead. Much of the information motorists need to drive safely in poor conditions is provided by pavement markings. The purpose of this study is to determine how well different types of pavement markings can be seen in the rain at night.

Procedures

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

1) Read this Informed Consent Form and sign it if you agree to participate.
2) Show your valid driver's license.
3) Complete vision tests.
4) Drive an instrumented vehicle on the Smart Road, and perform visual tasks regarding pavement markings. Video and audio data of the vehicle interior, including video of your face, will be collected during the drive.
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) Complete questionnaires.
7) 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.

II. Risks

There are risks or discomforts to which you may be exposed in volunteering for this research.

They include the following:

For the eye testing prior to the experiment, you may feel discomfort from having a small LED light briefly shined into your eyes.

For the Smart Road portion of the study, the risks to you are similar to the risks you would encounter driving an unfamiliar vehicle in rainy weather conditions at night on a road with minimal traffic at up to 25 miles per hour.

Please be aware that events such as equipment failure, changes in the test track, stray or wild animals entering the road, and weather changes may require you to respond accordingly. Finally, due to the length of the study, you may experience fatigue.

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

1) An experimenter will monitor your driving and will ask you to stop if he or she feels the risks are too great to continue.
2) You will be required to maintain a low speed throughout the driving session (20 mph in rain and 25 mph in clear weather).
3) You are encouraged to take breaks if you desire, and may withdraw from the study at any time.
4) The experimenter will be present while you are driving. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe and legal manner.
5) You will be required to wear the lap and shoulder belt restraint system while in the car. The vehicle is equipped with a driver's side and passenger's side airbag supplemental restraint system, fire extinguisher and first-aid kit. The experimenter will also have a cell phone.
6) The Smart Road will be closed to traffic not involved in the study.
7) In the event of a medical emergency, or at the participant’s request, VTTI staff will arrange medical transportation to a nearby hospital emergency room. The participant will be told that he/she may elect to undergo examination by medical personnel in the emergency room.
8) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
9) Testing will be cancelled in the event of icy pavement, or poor visibility.
10) On-road experimenters are in contact with in-vehicle experimenters to notify them when the experimental conditions are ready.
11) On-road experimenters will stay off the roadway behind guardrails when the participant vehicle is in sight.

In the event of an accident or injury in an automobile owned or leased by Virginia Tech, 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. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, worker's compensation does not apply to volunteers; therefore, if not in the 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. For example, if you were injured outside of the automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by your insurance.

III. 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. Participation in this study will contribute to the improvement of driver safety.

IV. 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 results if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed. At no time will the researchers release data identifiable to an individual to anyone other than VTTI staff working on the project without your written consent. All written and digital data associated with this project will be destroyed after seven years.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

V. Compensation

You will be paid $20.00 per hour for participating. You will be paid at the end of this study in cash. If you choose to withdraw before completing all scheduled experimental tasks, you will be compensated for the portion of time of the study for which you participated. If these payments are in excess of $600 dollars in any one calendar year, then by law, Virginia Tech is required to file Form 1099 with the IRS. For any amount less than $600, it is up to you as the participant to report any additional income as Virginia Tech will not file Form 1099 with the IRS.

VI. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. 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 question or respond to experimental situations without penalty. If you choose to withdraw while you are driving on the test route, please inform the experimenter of this decision and he/she will provide you with transportation back to the building.

VII. 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. This form is valid for the period listed at the bottom of the page.

VIII. Subject's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties of any type.
2. To wear your seat and lap belt.
3. To abstain from any substances that will impair your ability to drive.
4. To obey traffic regulations and maintain safe operation of the vehicle at all times.
5. To adhere to the posted speed limits on public roads, and to a 25 mph (maximum) speed limit on the Smart Road for this experiment.

IX. 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 may withdraw at any time without penalty. I agree to abide by the rules of this project.

Participant's Name (Print)	Signature	Date

Experimenter's Name (Print)	Signature	Date

Should I have any questions about this research I may contact:

Ron Gibbons	231-1500
Chris Edwards	231-1500
Brian Williams	231-1500

If I should have any questions about the protection of human research participants regarding this study, I may contact:

Dr. David Moore,
Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects
Telephone: (540) 231-4991;
Email: moored@vt.edu;
Address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.--

APPENDIX D

W-9 FORM

Substitute

Form W-9

Certification of Taxpayer Identification Number for Individuals

Please check one:

_____ I am a U S citizen, or

_____ I have been granted permanent residency (green card holder), or

_____ I am a Resident Alien for tax purposes and have contacted Janet Kunz at 540-231-3754 or jakunz@vt.edu to discuss the additional documentation that is required by federal law.

1. Name

First: ____________________ Middle: __________________ Last: __________________________

2. U.S. taxpayer identification number (required)

____

3. Address (number, street, and apt. or suite no.)

____

4. City, State and ZIP code

____

Certification:
Under the penalties of perjury, I declare that to the best of my knowledge and belief, the above statements are true, correct, and complete and that:

1. The number shown on this form is my correct taxpayer identification number, **and**

2. I am not subject to backup withholding because: (a) I am exempt from backup withholding, or (b) I have not been notified by the Internal Revenue Service (IRS) that I am subject to backup withholding as a result of a failure to report all interest or dividends, or (c) the IRS has notified me that I am no longer subject to backup withholding, **and**

3. I am a U.S. person (including a U. S. resident alien).

Certification Instructions. You must cross out item 2 above if you have been notified by the IRS that you are currently subject to backup withholding because you have failed to report all interest and dividends on your tax return.

Signed:_________________________________ Date: ______________

Revised 1/05

APPENDIX E

HEALTH SCREENING FORM

Participant #__________________

1. Current age: _________ years old

2. Gender: Male Female

3. Are you in good general health? Yes No

   If "No", list any health-related conditions you are experiencing or have experienced in the recent past.

   ____

   ____

   ____

4. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	Yes	No
Hangover	Yes	No
Headache	Yes	No
Cold symptoms	Yes	No
Depression	Yes	No
Allergies	Yes	No
Emotional upset	Yes	No

5. Do you have a history of any of the following?

   Visual Impairment Yes No

   (If yes, please describe.)

   ____

   ____

   ____

   Seizures or other lapses of consciousness Yes No

   (If yes, please describe.)

   ____

   ____

Any disorders similar to the above or that would impair your driving ability — Yes No

(If yes, please describe.)

____

____

____

6. List any prescription or non-prescription drugs you are currently taking or have taken in the last 24 hours that may interfere with your ability to drive (e.g., medications that may cause drowsiness, medications that may make you dizzy).

   ____

   ____

7. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours.

   ____

8. Have you had any eye injury or surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery)

   □ Yes: Type of surgery/injury_____________________________________
   □ No

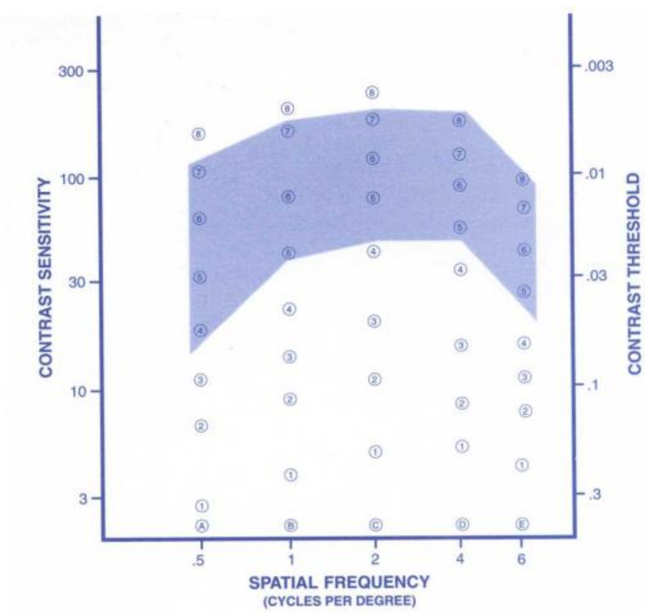
- -

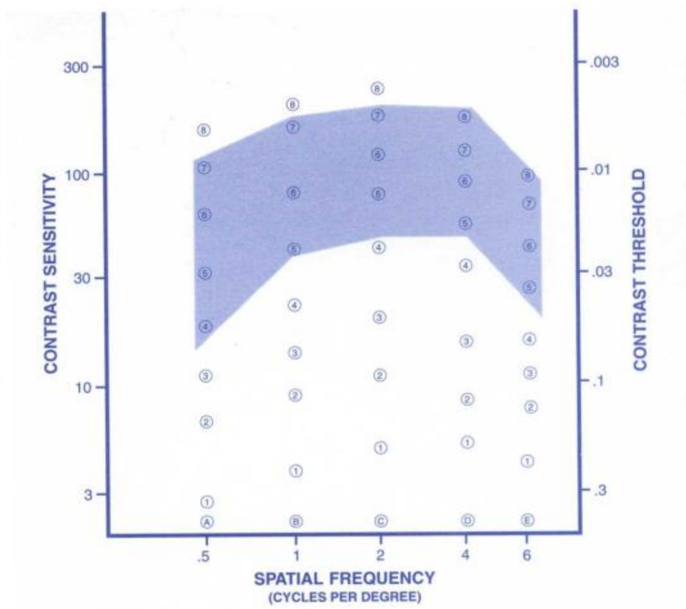
For experimenter use:

Visual test (Snellen): _______________

Color vision: _____________
____
____
____
____
____

Contrast Sensitivity:





APPENDIX F

PRE-DRIVE QUESTIONNAIRE

1. What is your age? __________years

2. What is your gender?   M   or   F

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

4. Approximately what is your annual mileage? __________miles

5. Are you…(circle one)
    a. Employed
    b. Student
    c. Retired
    d. Unemployed

6. If you are employed, do you drive as part of your work requirement? (circle one)
    a. Yes
    b. No

7. What is the make/model/year of your current vehicle?
    Make_______________
    Model______________
    Year________________

8. Do you have a secondary vehicle? __________
    If yes:
    Make _______________
    Model ________________
    Year _______________
9. Which type of transmission does your primary vehicle have? (circle one)
    a. automatic
    b. manual (stick, straight, standard)
    c. select shift (automatic with a manual option)

10. In your driving experience, how much of a problem has spray and splash been:

1	2	3	4	5	6	7	?
1	2	3	4	5	6	7	

Very Little   Very Much

APPENDIX G

PAYMENT RECEIPT

VirginiaTech TRANSPORTATION INSTITUTE

DRIVING TRANSPORTATION WITH TECHNOLOGY

Thank you for your collaboration and interest in this study. The time that you have taken to evaluate these new technologies is greatly appreciated. The results of this evaluation process will contribute to pavement marking designs and driver safety.

If you have any questions please do not hesitate to contact us.

Date:	___/__/__
Time In:	____:____
Time Out:	____:____
Time	____:___

TOTAL TIME: ___________________

TOTAL PAYMENT: _______________

VTTI Staff Signature: _______________

*Please note that payments you receive in accordance with this research are considered taxable income. If payment exceeds $600.00 in any one calendar year, Virginia Tech is required to file a 1099 form with the IRS. For amounts less than $600.00, you are responsible for reporting additional income, but no 1099 tax forms will be filed with the IRS.