FINAL REPORT

DETERMINING THE EFFECTIVENESS OF PAVEMENT MARKING MATERIALS

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ABSTRACT

The purpose of this research was to determine the safety, motorist opinion, and cost-effectiveness of pavement marking materials used by the Virginia Department of Transportation and to develop guidelines, where possible, as to when each type of material should be used. Interstate and primary road segments that had been remarked with a different type of pavement marking material were identified to perform a before-and-after accident analysis. When possible, segments that were remarked using the same pavement marking material were included to provide comparison sections. The number of sites and accident count data were insufficient to support a finding that the use of a particular pavement marking material reduces the number of target accidents.

The results of a motorist survey indicated that the participating drivers were more satisfied with pavement markings with higher retroreflectivity values than those with lower values. Participating drivers over the age of 65 were generally less satisfied with the brightness of the pavement markings than were participating drivers under the age of 65.

Using a large contract for paint was the most cost-effective for two-lane roads under most volume conditions and four- and six-lane low-volume roads. Using polyurea and a large contract for paint were the most cost-effective for high-volume two- and four-lane roads. Polyurea and waffle tape were the more cost-effective durable markings for high-volume six-lane roads.

Changes in the use of pavement markings were recommended. Specifically, the Virginia Department of Transportation should (1) consider increasing the use of large paint contracts and minimizing its use of small paint contracts when possible; (2) consider a performance-based specification for durable markings; (3) continue consideration of a holistic approach for pavement management and markings, and (4) re-evaluate its pavement marking policy and include the recommendations of this study.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) uses various types of material for marking pavements. The three primary types are paint, thermoplastic, and waffle tape (other types include epoxy and polyester). These three materials account for more than 90 percent of the pavement markings in the Commonwealth. Current VDOT policy, as put forth in the Traffic Engineering Division's Memorandum Number TE-261, states that "the Department has decided to use Type B, Class VI pavement markings for all markings on Limited Access Highways except for the stop lines and crosswalks on the ramps."[1] In FY 97, VDOT spent approximately $14.6 million on pavement markings on the interstate and primary systems. In FY 98, this amount rose to approximately $16.8 million.

Waffle tape pavement markings (such as VDOT's Type B-VI tape) provide a higher coefficient of retroreflectivity than either paint or thermoplastic markings. Additionally, waffle tape markings with a 6-year service life generally need to be replaced less frequently than paint markings (1-year service life) or thermoplastic markings (3-year service life), thereby reducing the number of installations, the impact on traffic flow, and the risk of accidents involving maintenance personnel.

Groups other than VDOT have studied various pavement markings with the goal of determining which is most cost-effective. However, since these studies were not performed in Virginia, their results may not be applicable because of different weather conditions, traffic volumes, pavement surface types, and installation procedures. However, the other studies tend to indicate that preformed markings (such as waffle tape) are not more cost-effective than other types of markings, even when the increased useful life of the preformed markings is taken into consideration.[2-4]

Members of VDOT management, at both the central and district offices, expressed concern about the cost-effectiveness of waffle tape and determined that an investigation of the cost-effectiveness of pavement marking materials was the number one item on the traffic research priority list.[5]

PURPOSE AND SCOPE

The purpose of this research was to determine the safety, motorist opinion, and cost-effectiveness of pavement marking materials used by VDOT and to develop guidelines, where possible, as to when each pavement marking material should be used.

VDOT's Maintenance Division plans to experiment with preventive pavement management strategies that will affect pavement markings. Consideration is being given to applying a seal coat to a pavement after about its third year of life as a means to extend its life. If this proves effective and becomes standard practice, then a pavement marking with a service life greater than 3 years (such as waffle tape) could have its service ended at 3 years, thereby decreasing its cost-effectiveness. There are also concerns about the use of new pavement mixtures such as Superpave and the potential value and impact of preventative maintenance seals on these mixtures. During the conduct of this study, the researchers were asked to incorporate VDOT's preventive maintenance strategy into the study scope and investigate preventive pavement management and pavement markings in an integrated or holistic approach.

RESEARCH DESIGN

The research design had three components, one for each of the study aspects of safety, motorist opinion, and cost-effectiveness.

The safety component involved selecting interstate and primary road segments, ideally each being at least 2 mi (3.2 km) long, throughout the Commonwealth on which to compare the safety of the pavement marking materials based on different levels of retroreflectivity. Segments that were remarked using a different material were identified to perform a before-and-after accident analysis. When possible, segments that were remarked using the same pavement marking material were included to provide comparison sections. In addition, an e-mail survey on the safety and exposure of VDOT marking crews was sent to all nine VDOT districts.

To measure motorist perceptions of various levels of brightness, a survey was administered using a videotape of markings as viewed from a vehicle driving through road sections with different markings.

Retroreflectivity and durability data from the National Transportation Product Evaluation Program, studies by the Virginia Transportation Research Council (VTRC), and other studies were used, where possible, to reduce the number of field trips required to collect data. The cost, retroreflectivity, and service life of each pavement marking material were used to determine cost-effectiveness. Cost based on service life only was also examined.

METHODS

Six tasks were conducted to achieve the study objectives: (1) a literature review, (2) an accident analysis, (3) a motorist survey, (4) a cost-effectiveness analysis, (5) a cost and service life analysis, and (6) monitoring of VDOT's pilot preventive pavement maintenance program.

Literature Review

Literature on pavement markings in general and the evaluation of pavement markings in particular was identified and reviewed. The Transportation Research Information Services and the VTRC library were major sources for identifying documents.

Accident Analysis and Safety of Marking Crews

Accident Analysis

The road segments used in the before-and-after accident analysis had been marked with a pavement marking material for at least 1 year and then remarked with a pavement marking material that was in place for at least 1 year. For most of the road segments, the pavement marking materials had been in place for 2 or more years. Accident data from VDOT's Highway Traffic and Records Information System were collected and analyzed for the sites identified.

The researchers used an observational before-after study approach with comparison groups as described by Hauer[10] to determine what impact, if any, pavement marking materials had on accidents.

Two sets of analyses were performed. In the first set (selected accidents), only accidents classified as sideswipe-in-the-same-direction and run-off-the-road accidents were included, since such accidents may have resulted from poor lane delineation. Accident data were collected for periods both before and after the pavement sections were remarked and grouped into daytime and nighttime accidents. Sideswipe-in-the-same-direction and run-off-the-road accidents at night were selected as the target accidents (accidents that are materially affected by the pavement marking material), and the same type of accidents that occurred during the day were selected as comparison accidents.

In the second set of analyses (all accidents), all accidents were included. As in the first set, accident data were collected for periods both before and after the pavement sections were remarked and grouped into daytime and nighttime accidents. All nighttime accidents were selected as the target accidents, and all daytime accidents served as the comparison accidents.

Safety of Marking Crews

To determine the safety of district marking crews, the survey shown in Appendix A was emailed to the nine VDOT district traffic maintenance operations managers.

Motorist Survey

To ascertain the perception of motorists regarding various levels of retroreflectivity, a questionnaire survey was employed (see Appendix B). The research team videotaped several sections of roadway at night from a vehicle traveling at the speed limit with low-beam headlights. The manual focus was used. The scenes were videotaped from the same vehicle by the same person, who was experienced in videotaping. The sections were on four-lane asphaltic-concrete divided highways, specifically I-64 and Route 29. Seven scenes, each 7 to 10 seconds long, were selected for review by test subjects. In most of the scenes, the retroreflectivity level or brightness of the pavement markings changed. The video images of the scenes were projected onto a screen that was at least 6 ft x 6 ft (1.8 m x 1.8 m) in a darkened room. In these scenes, the subjects were asked to focus on the right edgeline and then answer questions regarding the right edgeline. The first scene was used as a practice question to allow the survey participants an opportunity to become familiar with the survey process and to understand what was expected of them.

A survey of motorists was selected because alternative approaches such as having each subject drive through the test sections would have been time-consuming and would have resulted in much smaller sample sizes. A driver simulator would have been beneficial, but one was not available. Obtaining a large sample of older drivers may have been difficult if the study involved actual driving at night because older drivers commonly avoid nighttime driving.

The survey was administered to four groups: a group attending a VTRC Traffic Research Advisory Committee, a third-year University of Virginia engineering class, and two groups of older citizens participating in activities at the Charlottesville Senior Center.

Cost-Effectiveness Analysis

The approach taken was to combine cost, effectiveness, and service life to measure cost-effectiveness. A similar approach was used in evaluating sign materials in a previous study by Cottrell: the measure of effectiveness was based on cost per brightness or retroreflectivity per service life.[11] Retroreflectivity for pavement markings is measured as millicandela per square meter per lux using a retroreflectometer. For simplicity, retroreflectivity is often expressed using only the first term, millicandela (mcd). The measure of cost-effectiveness used for this study was that cost-effectiveness equals the total installed cost per mile divided by the expected service life in years divided by the average retroreflectivity for its expected service life. The resulting measure is cost per mile per millicandela per year.

The actual costs of installing pavement markings and service life were those currently paid or incurred by VDOT. The costs of pavement markings for a 1-mi (1.6-km) section were estimated for two-lane roads and for one direction of four- and six-lane roads. The two-lane road had edgelines and double yellow centerlines. The one direction of a multi-lane roadway scenario had a white and a yellow edgeline and lane or skip lines. The following type of pavement markings were included:

1. paint under three scenarios of line installers: VDOT staff, a large maintenance contract, and a construction (or small) contract

2. thermoplastic

3. waffle tape

4. epoxy

5. polyurea.

The costs for painting vary greatly under the different scenarios. The polyurea marking (also called Liquid 1200) is a new material consisting of a two-component 100 percent solid polyurea coating material. VDOT is testing this material to determine if it is eligible for placement on VDOT's approved materials list. Since this decision is scheduled for February 2001, the material was included for comparison purposes. With the exception of the painting by VDOT staff, all markings were installed under contract.

The initial retroreflectivity readings were based on data obtained by VTRC, VDOT's Materials Division, or other state departments of transportation (DOTs) through the National Transportation Products Evaluation Program. The readings were measured using retroreflectometers with 15-m geometry. The newer, state-of-the-art retroreflectometers use 30-m geometry. Since retroreflectivity data based on 15-m geometry were not available for the polyurea marking, the 15-m based data were estimated using retroreflectivity data for the tape from both 15- and 30-m geometry retroreflectometers and limited data for the liquid markings from a 30-m geometry retroreflectometer. The retroreflectometer readings were for white markings only.

The service life estimates were made by VDOT's district staff responsible for maintaining the various kinds of markings on VDOT maintained roads. Service life may vary greatly depending on a number of variables including geographic location, types, and number of vehicles using the roadway, road geometrics, and snow plowing operations. For the tape, the service life was set as being equal to the warranty period. For the liquid system, the service life used was the expected service life stated by the manufacturer. A retroreflectivity value of 150 mcd/m^2/lux was for the end of service life. The average retroreflectivity was the average between the initial and end of service life retroreflectivity values.

Traffic delay resulting from the installation of pavement markings was estimated by conducting computer runs of CORSIM. The runs were performed for two-, four-, and six-lane road sections for a variety of traffic-volume conditions rated as low, medium, and high. A 1-mi (1.6-km) section was used with the pavement marking vehicle in the right lane. The speed of this mobile operation was assumed to be 7 mph (11 km/h). It was assumed that 2 percent of the vehicles were trucks. This percentage may be low. However, for relative comparison purposes between marking materials, this simulation and assumptions were adequate. The intent was to obtain the relative estimate of the impact of delay on the cost of pavement marking installation as the volume and roadway changes.

The vehicle hours of delay were converted to a cost for delay. Chui and McFarland estimated the value of an hour of travel for typical vehicles on four-lane Texas highways in 1985 dollars: $10.40 for passenger vehicles and $19.00 for trucks.[12] The consumer price index for all urban consumers was 107.6 in 1985 and 166.6 in 1999.[12] Therefore, the values were inflated by a factor of 166.6/107.6, to $16.10 and $29.42, respectively. A weighted average of 1 hour of travel was multiplied by the vehicle hours of delay to obtain the cost of delay for pavement marking installation.

Cost and Service Life Analysis

Whereas cost-effectiveness analysis considers retroreflectivity and the costs of congestion delays incurred by the motorists because of pavement marking installation, the cost and service life considers service life as the only benefit. The analysis was applied to one side of a four-lane divided highway, and annual cost and cost over several time periods were reviewed.

Monitoring of VDOT's Pilot Preventive Pavement Maintenance Program

To support this effort, representatives from VDOT's maintenance, materials, and traffic engineering divisions and staff from VTRC representing the asphalt pavement, maintenance, and traffic research areas met to discuss this task. It was agreed that the researchers would monitor VDOT's pilot preventive pavement maintenance program and report on the results.

RESULTS AND DISCUSSION

Literature Review

Because pavement marking materials have changed over time, only documents authored in 1990 or later are presented here. Some earlier documents were reviewed for their study approach.

Becker and Marks of the South Dakota DOT studied the cost-effectiveness of their current pavement markings and several alternatives.[2] Water-based paint was the most cost-effective for rural areas. No markings were identified as cost-effective for urban areas (water-based paint was not used in urban areas but was suggested for future use).

Perrin, Martin, and Hansen analyzed the cost and durability of paint, epoxy, and tape in Utah.[3] Paint was 2 to 4 times less expensive than epoxy and 4 to 7 times less expensive than tape. Solvent-based paint was the most cost-effective material, and tape was the least cost-effective. The results were based on retroreflectivity data, annual average daily traffic levels, and costs.

The Kansas DOT uses a brightness benefit factor, BBF, in its pavement marking policy.[4] *BBF* was defined as a benefit/cost ratio for pavement marking materials representing the combined effects of the retroreflectivity, durability, installed cost, and the project or pavement service life. The BBF is the product of the average useful retroreflectivity over the anticipated service life of the project and the service life of the project, divided by the cost per unit length (millicandela-years per dollar-meter). Tables were provided that identified the BBF for different pavement marking materials grouped by the pavement service life remaining (nine groups from more than 7 years to less than or equal to 1 year) and categorized by three average daily traffic (ADT) groups (less than 5,000, 5,000 to 50,000, more than 50,000). Thermoplastic had the highest BBF for all ADT groups when the pavement service life remaining was 5 years or greater, for the higher two ADT groups when the pavement service life remaining was 3 and 4 years, and for the higher ADT group for all remaining groups. Epoxy had the highest BBF for the lowest ADT group when the pavement service life remaining was 2 to 4 years and for the middle ADT group when the pavement service life remaining was less than or equal to 1 to 2 years. Paint had the highest BBF for the lowest ADT group when the pavement service life remaining was 1 year or less.

Chapman conducted a study on cost-effective marking and delineation materials for the California DOT.[6] Although no recommendations were made, the conclusions described the performance of different materials with emphasis on their chemical composition, the installation process, and laboratory test performance. It was concluded that thermoplastic is an alternative to paint and epoxy performs well on previously applied painted lines.

The Federal Highway Administration's *Roadway Delineation Practices Handbook* by Migletz et al. provided a comprehensive description of pavement marking materials, including a description of each material and its properties, performance, service life, installation, maintenance, and removal costs.[7] Although no cost-effectiveness analysis was performed, this is an excellent reference for pavement markings.

Rumar and Marsh conducted a literature review on lane markings in 1998.[8] Although the emphasis was on driver needs and visibility of markings, durability, maintenance, and cost were considered for paint, thermoplastic, preformed tape, epoxies, and polyester.

Lee, Maleck, and Taylor performed an analysis of the correlation between pavement marking visibility and nighttime accidents for the Michigan DOT.[9] With the limited data, no correlation was found. Several factors that may have influenced the results were identified including the number of retroreflectivity measurements, the precision of the retroreflectometer, the small number of relevant accidents, and the complexity of the causes of traffic accidents.

Accident Analysis and Safety of Marking Crews

Accident Analysis

The researchers contacted each of VDOT's nine construction districts to obtain candidate sites for the accident analyses. Thirty-two sites were identified. The average length of the sites was approximately 3.6 mi (5.8 km), and the average duration of each of the before and after study periods was approximately 2.5 years. Of the 32 identified sites, only 22 sites could be used because of accident data limitations (the analysis method selected requires that the number of accidents in the before period with the treatment be greater than zero). Table 1 presents the sites included in the analyses and categorizes them by pavement marking materials, whether resurfacing occurred when the roads were remarked, and whether raised pavement markers were present. When they were present, they were present both before and after the road was remarked.

Table 1. Numbers of Sites Included in Analyses for Both Sets of Analyses

	Paint-Paint			**Paint-Thermo-plastic**	**Paint-Tape**	**Thermoplastic-Thermoplastic**		**Thermoplastic-Tape**
Resurface-RPM	No-no	No-yes	Yes-no	Yes-no	Yes-yes	Yes-no	No-yes	Yes-yes
Selected accidents	2	2	3	3	2	3	3	2
All accidents	2	2	3	3	2	5	3	2

Some sites were viewed as control groups since the pavement markings were the same in the before and after conditions and the road sections were not resurfaced when the pavement markings were replaced. One would expect that any statistically significant change in the number of accidents at these sites would be either attributable to factors other than the pavement marking material or simply a result of the random variation inherent in accident occurrences. However, it is also possible, because of the small sample sizes, that any statistically significant change in the number of accidents in the test sites (where the pavement marking material changed or resurfacing occurred) could be attributed to random variation in the accident data.

The numbers of accidents in the sets of analyses varied greatly. Table 2 presents the mean and standard deviation of the number of accidents in the treatment (nighttime accidents) and comparison (daytime accidents) data sets for both sets of analyses.

The relatively high standard deviations, as compared to the means, are due to the variability in the accident count data. In the analyses of the selected accidents, the number of

Table 2. Statistics on Target Accidents in Treatment and Comparison Data Sets

Analyses Sets	Treatment (Night)		Comparison (Day)	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**
Selected accidents	3.175	3.145	4.525	3.942
All accidents	7.773	7.281	15.818	15.204

target accidents in the before period of the treatment sites ranged from 1 to 15, and the number of target accidents in the before period of the comparison sites ranged from 1 to 16. In the analyses of all accidents, the number of target accidents in the before period of the treatment sites ranged from 1 to 30, and the number in the comparison sites ranged from 1 to 52.

As mentioned earlier, the researchers used an observational before-after study approach with a comparison group, including variable definitions, as described by Hauer.[10] The two variables of particular interest in this study were θ and σ_θ and are defined, respectively, by Hauer[10] as the estimate of the index of effectiveness and the estimate of the standard deviation of the estimated mean index of effectiveness where $\theta < 1$ corresponds to an estimated reduction in the number of target accidents and $\theta > 1$ corresponds to an estimated increase in the number of target accidents.

The results of the analyses of the selected accidents, where the target accidents were defined as sideswipe-in-the-same-direction and run-off-the-road accidents, are presented in Table 3. Table 4 presents the results of the analyses where all accidents were considered.

Table 3. Effectiveness of Marking Material on Selected Accidents

Marking Material		Remarking Conditions			
Before	**After**	**Resurfaced**	**RPMs**	**θ**	**σ_θ**
Paint	Paint	No	No	0.24	0.15
Paint	Paint	No	Yes	0.31	0.18
Thermoplastic	Thermoplastic	No	Yes	0.54	0.22
Paint	Paint	Yes	No	1.15	0.56
Paint	Thermoplastic	Yes	No	0.82	0.47
Paint	Waffle Tape	Yes	No	0.53	0.28
Paint	Thermoplastic	Yes	Yes	0.22	0.15
Thermoplastic	Waffle Tape	Yes	Yes	1.17	0.66

Table 4. Effectiveness of Marking Materials on All Accidents

Marking Material		Remarking Conditions			
Before	**After**	**Resurfaced**	**RPMs**	**θ**	**σ_θ**
Paint	Paint	No	No	0.70	0.33
Paint	Paint	No	Yes	0.49	0.23
Thermoplastic	Thermoplastic	No	Yes	0.89	0.29
Paint	Paint	Yes	No	1.07	0.33
Paint	Thermoplastic	Yes	No	0.94	0.32
Paint	Waffle Tape	Yes	No	1.01	0.22
Paint	Thermoplastic	Yes	Yes	0.25	0.15

Thermoplastic	Waffle Tape	Yes	Yes	1.59	0.91

The researchers selected 0.05 (5 percent) as the probability of a type I error in the hypothesis tests. The null hypothesis to be tested was that each pavement marking material did not affect the number of target accidents (h_0: $\theta = 1$). The alternate hypothesis was that each pavement marking material did affect the number of target accidents (h_1: $\theta \neq 1$). Given that the sample sizes were small and there were insufficient data to determine the appropriate distributions of the data, the researchers assumed that the data were normally distributed and performed *t* tests. Even in this best case scenario, there was insufficient evidence to reject the null hypothesis in each and every *t* test.

Safety of Marking Crews

Six districts responded to the e-mail survey on the safety of marking crews. The reduced exposure of marking crews to traffic when remarking road sections with waffle tape is significant. With a service life warranty of 6 years, there is typically little maintenance required. The survey revealed that crews are marking pavements an average of 157 days per year. Most districts have two crews available, and each crew marks an average of 19 mi (30.4 km) of roadway per day. During 1999, there was one accident involving a marking crew while marking lines in the six districts. For the 3-year period 1997 through 1999, there were nine. Seven were property damage only, and two involved injuries. The survey also found that a substantial percentage of markings are installed by contract: 60 percent of the time on interstates, 30 percent on primary roads, and 50 percent on secondary roads.

Motorist Survey

Only five of the initial seven scenes were used—one was excluded because it was used as a practice scene and another was excluded because the change from the first site to the second site in the scene occurred so early in the scene that many of the survey participants missed the first site and thus did not realize that the scene contained two sites. Table 5 presents the pavement marking materials and retroreflectivity readings of the seven scenes used.

Table 5. Marking Materials and Retroreflectivities (mcd/m^2/lux) of Scenes in Motorist Survey

	First Site		Second Site	
Scene	**Marking Material**	**Retroreflectivity**	**Marking Material**	**Retroreflectivity**
1 (Not Used)	Paint	190	Paint	195
2	Waffle Tape	698	Paint	183
3	Paint	104	Waffle Tape	649
4	Thermoplastic	145	Thermoplastic	145
5	Waffle Tape	686	Waffle Tape (old)	239
6 (Not Used)	Thermoplastic	215	Waffle Tape	692
7	Waffle Tape	649	Paint	104

Results of the survey, presented in Table 6, indicated that pavement markings with retroreflectivity readings less than 300 mcd/m^2/lux were classified as acceptable approximately 53 percent (mean value) of the time, whereas markings with retroreflectivity readings greater than 600 mcd/m^2/lux were classified as acceptable approximately 92 percent (mean value) of the time.

Table 6. Survey Participants' Evaluations of Retroreflectivity Readings (mcd/m^2/lux)

Readings	Older 1	Older 2	Students	TRAC	Everyone
104	13/22 (59.1%)	14/28 (50.0%)	33/44 (75.0%)	17/28 (60.7%)	77/122 (63.1%)
104	14/23 (60.9%)	11/23 (47.8%)	28/45 (62.2%)	21/27 (77.8%)	74/118 (62.7%)
145	6/21 (28.6%)	5/24 (20.8%)	15/30 (50.0%)	11/28 (39.3%)	37/103 (35.9%)
145	6/21 (28.6%)	6/24 (25.0%)	15/30 (50.0%)	11/28 (39.3%)	38/103 (36.9%)
183	15/24 (62.5%)	15/24 (62.5%)	17/43 (39.5%)	16/28 (57.1%)	63/119 (52.9%)
239	14/22 (63.6%)	13/24 (54.2%)	27/41 (65.9%)	19/27 (70.4%)	73/114 (64.0%)
649	18/22 (81.1%)	24/28 (85.7%)	44/44 (100%)	28/28 (100%)	114/122 (93.4%)
649	18/23 (78.3%)	16/23 (69.6%)	44/45 (97.8%)	27/27 (100%)	105/118 (89.0%)
686	21/22 (95.5%)	19/24 (79.2%)	40/41 (97.6%)	26/27 (96.3%)	106/114 (93.0%)
698	20/24 (83.3%)	22/24 (91.7%)	42/43 (97.7%)	27/28 (96.4%)	111/119 (93.3%)

Statistical tests of proportions were conducted to determine if the two participant evaluations each of retroreflectivity readings of 104, 145, and 649 mcd/m^2/lux were statistically equivalent for each of the four groups. The researchers assumed that the normal approximation of the binomial distribution was valid and used the appropriate t statistic value in each test, based on the number of degrees of freedom. For each of the three pairs of samples, for each group, the results of the tests indicated that there was no statistically significant difference in the participants' perceptions of the pavement markings.

Statistical tests of proportions were conducted to determine if the participants over the age of 65 were equally satisfied (statistically) with pavement markings of different retroreflectivities as the participants under the age of 65. Two sets of tests were performed. In the first set, the sample observations of the two readings each of retroreflectivity readings of 104, 145, and 649 mcd/m^2/lux were pooled. In the second set, the first observations of retroreflectivity readings of 104, 145, and 649 mcd/m^2/lux were used (the second set was viewed as data to confirm the validity of the first set of observations). The only difference in the results was the participants' evaluation of the 104 mcd/m^2/lux retroreflectivity marking—in the pooled set, there was sufficient evidence to conclude that the older and younger participants were drawn from separate populations, whereas in the non-pooled set, there was insufficient evidence to conclude that they were drawn from different populations. Since the second set of analyses was more conservative (smaller sample sizes), the results of the second set of tests are presented in Table 7. Since the sample sizes of the survey populations tested were small and the participants were not randomly selected, these results should be interpreted as observations and not as a reflection of the general population.

Statistical tests of proportions were conducted to determine if the participants as a whole were equally satisfied (statistically) with pavement markings with retroreflectivity readings less than 300 mcd/m^2/lux as they were with markings with retroreflectivity readings greater than 600

Table 7. Comparison of Satisfaction Levels of Older and Younger Participants

Readings ($mcd/m^2/lux$)	*N* Older	*P* Older	*N* Younger	*P* Younger	*P* Overall	Proportion Test[1]
104	50	0.5400	72	0.6944	0.6311	-1.7383
145	45	0.2444	58	0.4483	0.3692	-2.1398
183	48	0.6250	71	0.4644	0.5292	1.7217
239	46	0.5870	68	0.6769	0.6406	-0.9815
649	50	0.8368	72	1.0000	0.9331	-3.5486
686	46	0.8700	68	0.9708	0.9301	-2.0729
698	48	0.8750	71	0.9719	0.9328	-2.0706

[1] t (two-sided, $\alpha = 0.05$, $\nu = 100$) ≈ 1.987; t (two-tailed, $\alpha = 0.05$, $\nu = \infty$) = 1.960.

$mcd/m^2/lux$. The results of the test are presented in Table 8 and indicated that there was sufficient evidence to conclude that the participants were more satisfied with markings with retroreflectivity readings greater than 600 $mcd/m^2/lux$ than they were with markings with retroreflectivity readings less than 300 $mcd/m^2/lux$. Again, these results should be taken as observations since the sample sizes were still relatively small and the participants were not randomly selected.

Table 8. Comparison of Participants' Satisfaction With Different Retroreflectivities ($mcd/m^2/lux$)

N < 300	*P* < 300	*N* > 600	*N* > 600	*N* Overall	Proportion Test[1]
458	0.5458	355	0.9321	0.7145	-12.0952

[1] t (two-tailed, $\alpha = 0.05$, $\nu = \infty$) = 1.960.

Cost-Effectiveness Analysis

Table 9 displays the initial retroreflectivity for white markings, installation cost, service life, and annualized installation cost (without accounting for the time value of money). Cost data for the materials were based on what VDOT currently pays for marking installation, except for the polyurea system, which was estimated by the manufacturer. All markings except paint (VDOT) are installed by private firms under contract with VDOT. VDOT staff installs the paint (VDOT). Paint (large contract), also referred to as a large paint contract, describes district-wide

Table 9. Initial Retroreflectivity, Installation Cost, and Service Life

Material	Initial Retroreflectivity ($mcd/m^2/lux$)	Install cost ($/lf)	Service life (yr)	Install cost/yr ($/lf/yr)
Paint (large contract)	250	0.04	1	0.04
Paint (VDOT)	250	0.08	1	0.08
Paint (small contract)	250	0.15	1	0.15
Thermoplastic	350	0.35	3	0.12
Epoxy	350	0.40	3	0.13
Polyurea	900	0.70	3	0.23
Waffle tape	1000	1.80	6	0.30

1 ft = 0.305 m.

contracts that include the installation of more than 1,000,000 linear feet (305,000 linear meters). In contrast, paint (small contract), also referred to as a small paint contract, describes small-scale contracts typically for one road section that may be required as part of a construction project. Paint is both the cheapest and least durable marking. For the durable markings, costs increase with retroreflectivity and service life.

There is a relationship between the size of the pavement marking job and the efficient use of the pavement marking equipment and crew. For remarking jobs, the marking crew typically can install markings all day so the cost of mobilizing the crew is spread over several miles of installed markings. For marking operations for construction projects and pavement overlay projects with a limited number of miles of marking, the mobilization costs are spread over the limited miles marked. Moreover, there is likely to be a substantial amount of time when the marking crew and equipment are idle. Therefore, it is more efficient and cost-effective to remark an existing roadway than to mark a short section of highway for a construction or overlay project. This variation in the efficiency and cost-effectiveness is greater where the equipment costs are higher. This is reflected in the costs for painting for a small contract versus a large contract. The costs for thermoplastic and epoxy are based on larger marking jobs.

The costs per mile for two-, four-, and six-lane roads are shown in Table 10. The costs for two-lane roads are highest because they are based on four continuous lines. The number of passes, i.e., the number of trips the marking truck makes through the road section to complete the marking installation, was based on actual marking practices. Three passes were used on two- and six-lane roads to minimize tracking of the markings, and two passes were used on four-lane roads. For example, on a two-lane road, one pass is made for each edgeline and the centerlines to minimize the vehicles crossing the pavement markings before they are dry.

Table 10. Cost for Installation ($/mi/yr)

Material	2-Lane Road	2 Lanes on 4-Lane Divided Highway	3 Lanes on 6-Lane Divided Highway
Paint (large contract)	840	472	524
Paint (VDOT)	1680	944	1048
Paint (small contract)	2450	1770	1965
Thermoplastic	2800	1377	1528
Epoxy	3150	1573	1747
Polyurea	4900	2753	3057
Waffle tape	6300	3540	3930

1 mi = 1.6 km.

The delay, delay cost per pass, and total delay cost for marking a 1-mi (1.6-km) section are shown in Table 11. Three scenarios were not used in further analyses. The two-lane 2000 vph scenario resulted in a very high, unrealistic level of delay. The low-volume scenarios for four- and six-lane roads resulted in very little, if any, delay. In practice, if vehicles are queuing up behind the paint truck, the marking crew will pull over before 1 mi (1.6 km) is painted to release the queue and reduce delay. Thus, two scenarios on two-lane roads with 0.5-mi (0.8-km) sections were added.

Table 11. Estimated Cost of Delay for Different Scenarios

Scenario	Delay (veh-hr/mi)	Delay Cost ($/mi/pass)	Total Delay Cost ($/mi)
2 lanes 400 vph	3.94	64	193
2 lanes 400 vph 1/2 mi	2.3	38	113
2 lanes 1000 vph	16.3	267	800
2 lanes 1000 vph 1/2 mi	13.7	224	673
2 lanes 2000 vph[1]	35	573	1718
4 lanes 800 vph[1]	0.05	1	2
4 lanes 2000 vph	1.6	26	52
4 lanes 4000 vph	22.5	368	736
6 lanes 1500 vph[1]	0	0	0
6 lanes 3000 vph	0.6	10	29
6 lanes 6000 vph	30.3	496	1488

[1]Not used in further analyses.
1 mi =1.6 km.

The total cost (both with and without delay), in ascending order, to mark two-lane roads is shown in Table 12. As the volume and delay costs increase, the total cost of the paint markings increases more than with the other markings because of higher delay costs attributed to the annual painting. For two-lane roads, the paint (large contract) is the most cost-effective under all volume conditions except for 1000 vph for 1/2 mi (0.8 km), where polyurea is most cost-effective.

The total costs (both with and without delay), in ascending order, to mark one side of a four- and six-lane divided highway are shown in Table 13. As the volume and delay costs increased, the total cost of the paint markings increased more than with the other markings because of higher delay costs attributed to the annual painting. For both roads, the paint under large contract and the paint by VDOT were the most cost-effective under the lower volume condition. For the higher volumes, the polyurea markings were most cost-effective.

Nighttime Pavement Marking

Although the cost of delay is a major reason for making durable markings more cost-effective on higher volume roads, on the highest volume roads, it is less of a factor because the pavement markings are installed typically at night to minimize delay to the traffic. The volumes are still respectable (i.e., medium volumes at night). The service life of paint is decreased where volumes are highest based on VDOT's experience. Therefore, cost-effective durable markings are appropriate at higher volume sites.

Table 12. Total Cost to Mark Two-Lane Roads ($/mcd/mi/yr)

Condition	Total Cost	Total Cost Without Delay	% Cost for Delay
400 vph			
Paint (large contract)	5.17	4.20	23.0
Paint (VDOT)	9.37	8.40	11.5
Polyurea	9.46	9.33	1.3
Thermoplastic	10.06	9.80	2.6
Waffle tape	10.96	10.96	0.0
Epoxy	11.46	11.20	2.3
Paint (small contract)	16.72	15.75	6.1
400 vph for ½ mi			
Paint (large contract)	5.33	4.20	21.2
Polyurea	9.48	9.33	1.5
Paint (VDOT)	9.53	8.40	11.8
Thermoplastic	10.10	9.80	3.0
Waffle Tape	10.96	10.96	0.0
Epoxy	11.50	11.20	2.6
Paint (small contract)	16.88	15.75	6.7
1000 vph			
Paint (large contract)	8.20	4.20	48.8
Polyurea	9.84	9.33	5.2
Thermoplastic	10.87	9.80	9.8
Waffle Tape	13.26	13.26	0.0
Epoxy	12.27	11.20	8.7
Paint (VDOT)	12.40	8.40	32.3
Paint (small contract)	19.75	15.75	20.3
1000 vph for ½ mi			
Polyurea	10.19	9.33	8.4
Paint (large contract)	10.93	4.20	61.6
Waffle tape	10.96	10.96	0.0
Thermoplastic	11.59	9.80	15.5
Epoxy	12.99	11.20	13.8
Paint (VDOT)	15.13	8.40	44.5
Paint (small contract)	22.48	15.75	29.9

1 mi =1.6 km; mcd = mcd/m^2/lux.

Cost and Service Life Analysis

The cost-effectiveness analysis was based on the assumption that brighter markings add value to motorists. The motorist survey indicated that there is not much benefit in using a marking with a retroreflectivity value greater than 600 mcd/m^2/lux compared with one with a value of 300 mcd/m^2/lux. Therefore, the analysis did not consider retroreflectivity as a benefit, only service life. Table 14 presents the annual cost of the pavement marking materials. The materials are listed from the lowest to the highest cost to mark one side of a four-lane divided highway. Because of the variability in the service life of paint, the costs for paint are shown for both a 6-month and a 1-year service life. Because of the relatively short study periods for the analyses and the usually assumed low values (between 4 and 6 percent) of the discount rate, the time value of money was not used in Tables 14 and 15.

Table 13. Total Costs to Mark One Side of Four- and Six-Lane Divided Highways ($/mcd/mi/yr)

Condition	Total Cost	Total Cost Without Delay	% Cost For Delay
2 lanes of 4-lane, 2000 vph			
Paint (large contract)	2.62	2.36	10.0
Paint (VDOT)	4.98	4.72	5.3
Polyurea	5.28	5.24	0.6
Thermoplastic	5.58	5.51	1.3
Waffle tape	6.16	6.16	0.0
Epoxy	6.36	6.29	1.1
Paint (small contract)	9.11	8.85	2.9
2 lanes of 4-lane, 4000 vph			
Polyurea	5.71	5.24	8.2
Paint (large contract)	6.04	2.36	60.9
Waffle tape	6.16	6.16	0.0
Thermoplastic	6.49	5.51	15.1
Epoxy	7.28	6.29	13.5
Paint (VDOT)	8.40	4.72	43.8
Paint (small contract)	12.53	8.85	29.4
3 lanes of 6-lane, 3000 vph			
Paint (large contract)	2.77	2.62	5.3
Paint (VDOT)	5.39	5.24	2.7
Polyurea	5.84	5.82	0.3
Thermoplastic	6.15	6.11	0.6
Waffle tape	6.83	6.83	0.0
Epoxy	7.03	6.99	0.6
Paint (small contract)	9.97	9.83	1.5
3 lanes of 6-lane, 6000 vph			
Polyurea	6.77	5.82	14.0
Waffle tape	6.83	6.83	0.0
Thermoplastic	8.10	6.11	24.5
Epoxy	8.97	6.99	22.1
Paint (large contract)	10.06	2.62	74.0
Paint (VDOT)	12.68	5.24	58.7
Paint (small contract)	17.26	9.83	43.1

1 mi = 1.6 km; mcd = mcd/m^2/lux.

Table 14. Pavement Marking Material Service Lives and Installation Costs ($/mi/yr)

Marking Material	Service Life	2 Lanes on 4-Lane Divided Highway	3 Lanes on 6-Lane Divided Highway	2 Lanes on 2-Lane Highway
Paint (large contract)	1 yr	472	524	840
Paint (large contract)	6 mo	944	1,048	1,680
Paint (VDOT)	1 yr	944	1,048	1,680
Thermoplastic	3 yr	1,377	1,528	2,800
Epoxy	3 yr	1,573	1,747	3,150
Paint (small contract)	1 yr	1,770	1,965	2,450
Paint (VDOT)	6 mo	1,888	2,096	3,360
Polyurea	3 yr	2,753	3,057	4,900

Paint (small contract)	6 mo	3,540	3,930	4,900
Waffle Tape	6 yr	3,540	3,930	6,300

1 mi = 1.6 km.

Table 15. Total Cost ($/mi) of Pavement Marking Materials for Different Study Periods

Marking Material	Service Life	1 Yr	2 Yr	3 Yr	4 Yr	5 Yr	6 Yr
Paint (large contract)	1 yr	472	944	1,416	1,888	2,360	2,832
Paint (large contract)	6 mo	944	1,888	2,832	3,776	4,720	5,664
Paint (VDOT)	1 yr	944	1,888	2,832	3,776	4,720	5,664
Thermoplastic	3 yr	4,131	4,131	4,131	8,262	8,262	8,262
Epoxy	3 yr	4,719	4,719	4,719	9,438	9,438	9,438
Paint (small contract)	1 yr	1,770	3,540	5,310	7,080	8,850	10,620
Paint (VDOT)	6 mo	1,888	3,776	5,664	7,552	9,440	11,328
Polyurea	3 yr	8,259	8,259	8,259	16,518	16,518	16,518
Paint (small contract)	6 mo	3,540	7,080	10,620	14,160	17,700	21,240
Waffle Tape	6 yr	21,240	21,240	21,240	21,240	21,240	21,240

1 mi =1.6 km.

The results presented in Table 14 show that even when the service life for paint is assumed to be 6 months, when installed under a large-scale contract, paint is the least expensive marking material, at a cost of approximately $950/yr to mark two lanes of a four-lane divided highway. To mark the same road with thermoplastic would cost approximately $1,400/yr, and the cost to mark the road with waffle tape would be approximately $3,500/yr.

Table 15 presents the total costs to keep one side of a four-lane divided highway marked with various pavement marking materials for study periods ranging from 1 to 6 years. The materials are presented in increasing order of cost based on a 6-year study period. It is assumed that a particular material will be replaced at the end of its service life with the same material.

As can be seen in Table 15, paint installed under a large-scale contract was the least expensive marking material regardless of the length of the study period. The costs of thermoplastic, epoxy, and paint (6-month service life) installed by VDOT were relatively similar for study periods between 3 and 6 years. Polyurea and waffle tape were the two most expensive marking materials, regardless of the length of the study period. However, the relative cost premium of polyurea and waffle tape (compared to thermoplastic and epoxy) decreased as the study period increased from 1 to 6 years.

Estimated Maximum Potential Savings

Eight of VDOT's nine districts maintain interstate highways. Based on interstate paving data from 1999 through 2000, VDOT on average resurfaces and installs waffle tape pavement markings on approximately 280 lane-mi (450 lane-km) of interstate highway per year in seven VDOT districts. VDOT's current policy is to install waffle tape (except for messages and temporary markings) on all interstate resurfacing projects. If VDOT were to use thermoplastic instead of waffle tape on interstate highway resurfacing projects, the most VDOT could save (based on the data in Table 15) would be approximately $1.8 million/yr. In addition, VDOT installs waffle tape on selected primary projects. VDOT could save additional monies if a marking material such as thermoplastic were used instead of waffle tape on these projects.

Decision-Making Tools for Pavement Marking Materials

There are numerous factors to consider when selecting a pavement marking material. These factors include the type and condition of the pavement, ability to install markings over the existing markings, level of service or quality of marking desired for a given highway, geographic location, climatic conditions, and pavement maintenance activities. These same factors greatly influence the service life of the markings. Because of the numerous factors to address and the magnitude of such an analysis, the researchers did not have sufficient information to develop guidelines concerning the use of particular pavement markings for particular situations.

An alternative method to use when making decisions about pavement markings, especially durable markings, is to consider a performance-based specification. For example, in this approach, the performance criterion could be that minimum retroreflectivity, 150 mcd for example, would be maintained for a given period, such as 3 years. Other criteria such as color and durability (material intact) ratings could also be considered. Such criteria would eliminate the need to consider many of the previously mentioned factors in the decision-making process.

LIMITATIONS OF THE STUDY

Three aspects of this study involved limitations that deserve mentioning: the retroreflectometers used to collect the retroreflectivity data; the use of videotape for the motorist opinion survey; and variability in retroreflectivity, cost, and service life.

15-Meter Versus 30-Meter Geometry Readings

Current practices are to use retroreflectometers with a 30-m geometry, which is supposed to approximate the typical aim of a headlight beam. The retroreflectivity data available for this effort were collected using 15-m geometry retroreflectometers. There is no known correlation between the 15- and 30-m geometry retroreflectometers. The results of the cost-effectiveness analysis may vary if data using a 30-m geometry are used.

Motorist Opinion Survey Using Videotape

There are limitations to the use of videotape for the motorist opinion survey. Although alternative approaches, such as having each subject drive through the test sections, would have been time-consuming and resulted in much smaller sample sizes, such an approach would place the driver in the actual environment. Moreover, when a video camera is used, the manner in which the iris of the camera adjusts to maintain an equal amount of light entering it may influence the visual difference between markings that are similar in retroreflectivity. For example, if the retroreflectivity of the pavement markings changed from 140 to 120 mcd/m^2/lux during a video scene, the automatic adjustment by the iris might affect how visibly the difference in retroreflectivity is displayed on the videotape. When the differences in retroreflectivity are relatively large, say, 140 and 300 mcd/m^2/lux, the iris adjustment has little or no impact. The survey approach is acceptable because most differences in retroreflectivity were large enough to result in little or no impact. Ideally, the camera should have been in the same position as the driver. For practical and safety reasons, the video camera was positioned at the right front passenger position as near to the windshield as possible.

Retroreflectivity, Cost, and Service Life

Retroreflectivity, cost, and service life are likely to vary. The retroreflectivity and service life vary based on the quality of the markings and the installation process. The values used in the analysis should change over time if there are improvements in any components of the material or installation process.

The average retroreflectivity of pavement markings was estimated by assuming that the reduction in retroreflectivity over time was linear. Based on data from tests by the National Transportation Product Evaluation Program, initial retroreflectivity values frequently drop precipitously in the first year of service. Typically, this is caused by the high initial retroreflectivity values because many glass beads are loaded on the top of the marking. These beads are worn off shortly after installation. Ideally, the average retroreflectivity should be based on retroreflectivity readings that track the change in retroreflectivity over the service life of each marking under similar conditions. In the absence of such data, the assumption was made.

Similarly, the service life estimates were made by VDOT district staff. The district staff makes the decision to replace markings based on a schedule derived from experience and/or visual observations. Retroreflectivity measurements are not routinely made as part of remarking decisions. Tracking the change in retroreflectivity over the service life of each marking under similar conditions would be of value in determining the service life.

VDOT's Pilot Preventive Pavement Maintenance Program

Because VDOT's pilot preventive pavement maintenance program is a work in progress, nothing definitive can be stated about its integration. As noted in the cost-effectiveness analysis, only one marking material, waffle tape, has a service life greater than 3 years. Therefore, if a seal coat were placed after the first 3 years of the life of a new pavement, it would coincide with the time to replace most of the marking material. If use of the preformed tape with a 6-year service life is planned, then VDOT should select a different marking material for use. A less likely option would be to seal cost the travel lanes only and avoid covering the markings. The impact this approach would have on preventive pavement maintenance is unknown.

CONCLUSIONS

- More accident sites and accident count data are needed to determine if the type of pavement marking material affects the number of target accidents.
- Drivers are more satisfied with pavement markings with higher retroreflectivity readings than with lower readings.
- Drivers over the age of 65 are generally less satisfied with the brightness of pavement markings than are drivers under the age of 65.
- The large paint contract is the most cost-effective for two-lane roads under most volume conditions and for four- and six-lane low-volume roads. Polyurea and paint installed under a large-scale contract are the most cost-effective for high-volume four-lane roads, and polyurea and waffle tape are the most cost-effective for high-volume six-lane roads.
- For durable markings, the order from most to least cost-effective is polyurea, thermoplastic, epoxy, and waffle tape for the low-volume roads. For higher volume roads, the order is polyurea, waffle tape, thermoplastic, and epoxy. When only the annualized installation costs are considered for a study period of 6 years, the order from least to most expensive is thermoplastic, epoxy, polyurea, and waffle tape.
- VDOT's Traffic Engineering Division's Memorandum Number TE-261[1] restricts VDOT's ability to use more cost-effective and less costly pavement marking materials on interstate highways.

RECOMMENDATIONS

1. Given the relatively low cost of large paint contracts, VDOT should consider increasing the use of this option. Similarly, VDOT should minimize its use of small paint contracts when possible.
2. For roads with higher volumes and higher levels of service, VDOT should use durable markings.
3. VDOT should consider a performance-based specification for durable markings. Any pavement marking policy should consider performance-based criteria.
4. VDOT should consider the expected service life of the road surface when determining the cost-effectiveness of pavement marking materials. Factors to consider when selecting a pavement marking material include type of pavement, ability to install markings over existing

markings, level of service or quality of marking desired for a given highway, and pavement maintenance activities (such as overlays and surface treatments).

5. VDOT's maintenance, materials, and traffic engineering divisions, with support from VTRC, should continue consideration of a holistic approach for pavement management and markings. Replacement of pavement markings should be a part of the preventive pavement management budget.

6. VDOT should re-evaluate the Traffic Engineering Division's Memorandum Number TE-261[1] and include Recommendations 2 through 5 of this study.

7. VDOT should conduct further analyses when data become available to determine if any of the durable pavement marking materials has a significantly greater, or lesser, impact on road safety than the others.

FUTURE CONSIDERATIONS

Over time, new or improved pavement marking materials are added to the market. The new materials will either compete directly with existing materials or create their own market niche. In either case, it is envisioned that information on the new products can be added to the information provided in this report to examine their value relative to other markings.

If approved for use, the polyurea markings will require time to become a viable option. The prototype trucks to install this marking must go through the traditional evaluation process to remove the bugs and improve the equipment and process. The capital investment must be acquired to produce the trucks and marking material based on the potential market for the markings, and the contractors must obtain the capacity and capability to use the trucks. It is expected that if this material is used, it will be installed under contract rather than being installed by VDOT staff. Consequently, this marking technology may be several years away from widespread use.

Some manufacturers are also developing pavement markings that are retroreflective under wet night conditions. If these markings are available, it will be necessary to determine the conditions where they may be useful.

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APPENDIX A

SURVEY ON SAFETY OF DISTRICT MARKING CREWS

Good Afternoon.

I am tying up some loose ends on the project on the cost-effectiveness of pavement marking materials. I am seeking information on the safety of line marking crews and their exposure to traffic. I hope that the answers are readily available. Please answer the following questions and email your response to me.

1. How many accidents were your pavement marking crews involved in during 1999 while marking lines? ___ No. of fatal accidents___ Injury accidents__ PDO___.

2. How many accidents were your pavement marking crews involved in during 1997 and 1998 while marking lines?___ No. of fatal accidents___ Injury accidents___ PDO___.

3. How many line marking crews do you have?__.

4. What is your best estimate of the number of days your line crews mark lines per year?____ (I plan to multiply this number by the number of line marking crews that you have to estimate the number of days your crews were exposed to traffic.)

5. What is your best estimate of the average number of miles of roadway marked per day?____

6. What percent of the line markings were done by contract in your district by highway system in 1999? Interstate____ Primary____ Secondary___ If 1999 was not a typical year, please provide the percentages for a typical year and draw a line through 1999.

7. Where do you use durable markings? Or to rephrase the question, under what conditions do you decide to use durable markings. All Interstate; All four lane divided facilities.

Please respond by email by Tuesday, July 18. If you have questions, please contact me. Thanks!

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APPENDIX B

PAVEMENT MARKING RATING SURVEY

We are interested in what you think about the visibility of the white line on the right edge of the road—the **right edgeline**. You will be seeing a videotape of several road sections at night. After viewing the videotape, answer the following questions for each scene.

SCENE 1

1. Was there any change in the appearance of the right edgeline during this scene?
   ___ Yes [Go to Question 2.] ____ No [Go to Question 4.]

2. Describe the change by checking one of the following:
   The first section of the edgeline was ____ a little brighter, ____ somewhat brighter, ___ much brighter.

   The second section of the edgeline was ____ a little brighter, ____ somewhat brighter, ____ much brighter.

3. Which section of the edgeline did you prefer?
   ____ the first section.
   ____ the second section.
   ____ no preference.

4. If you were driving, would the edgelines in both sections be bright enough for you?
   ____ Yes ____ No.
   If no, which edgeline was not bright enough? ____ first section ____ second section
   ____ both or the entire scene.

5. Comments
   ____
   ____
   ____
   ____
   ____

[NOTE: This set of questions is repeated six times each on a separate page for scenes 2 through 7.]

PLEASE TELL US A LITTLE ABOUT YOURSELF.

Your age (in years): _____

___ Male ___ Female

How would you rate your night vision?
____ Excellent ____ Good ____ Fair ____ Poor

How frequently do you drive at night?
____ Often ____ Occasionally ____ Rarely ____ Never

On average, how often do you drive?
____ Daily ____ 3-6 times per week ___ 1-2 times per week ____ 1-3 times per month
____ Less than 1 time per month

Provide any general comments on the evaluation.
____
____
____
____
____

Thank you!