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Nighttime Visibility of In-Service Pavement Markings, Pavement Markers, and Guardrail Delineation in Alaska (with and without Continuous Lighting)

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13. ABSTRACT (Maximum 200 words)

This research determined the visibility of in-service pavement markings along lighted and unlighted highway sections, and compared visibility of in-service pavement markings to the FHWA proposed minimum retroreflectivity levels for the Alaska Department of Transportation and Public Facilities. In order to measure the visibility, researchers measured nighttime luminance in the field with a using a customized piece of data collection equipment consisting of an industrial quality hand truck, a regulated switching power supply, a global positioning system receiver, a light source, a laptop computer, and a charged couple device photometer.

Researchers found that all of the pavement markings tested in this study would be in compliance with the Federal Highway Administration proposal. Continuous roadway lighting provided better visibility of pavement markings at longer distances than unlit highways. Along dark rural highways, the visibility of the raised retroreflective pavement markers and guardrail delineation tabs were greater than the pavement markings. All data collected in this project were under dry weather conditions.

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TABLE OF CONTENTS

Page

List of Figures vi
List of Tables vii
List of Acronyms viii
Acknowledgements ix
Abstract x
Summary of Findings xi
CHAPTER 1. INTRODUCTION 1
  Study Objectives 1
  Method 2
  Study Sites 4
CHAPTER 2. RESULTS 9
  Pavement Marking Visibility 9
  RRPM and Guardrail Delineator Visibility 14
CHAPTER 3. SUMMARY 19
  Concluding Remarks 19
  Wet Conditions 20
REFERENCES 21

LIST OF FIGURES

Page

Figure 1. Data Collection Equipment. 4
Figure 2. Photographs of Dimond Blvd. in 2007 (4-year old in-laid MMA). 5
Figure 3. Typical CCD Image for 44m Measurements.. 8
Figure 4. Pavement Marking Visibility Levels at 44 Meters... 12
Figure 5. Pavement Marking Visibility Levels at 54 Meters... 13
Figure 6. Pavement Marking Visibility Levels at 64 Meters... 14
Figure 7. Visibility Levels of Delineation Treatments at MP9 on Rezanof Drive. 15
Figure 8. Original RRPM Placement on Rezanof Dr. (circa 2005)... 16
Figure 9. Images of Center Line RRPMs after Restriping with Paint. 16
Figure 10. Visibility Levels of Delineation Treatments at MP2 on Rezanof. 17
Figure 11. Images from MP2 on Rezanof Drive on Kodiak.. 18

LIST OF TABLES

Page

Table 1. Study Site Characteristics. 6
Table 2. Comparison of Measured and Proposed Minimum Retroreflectivity Levels. 9
Table 3. Pavement Marking Visibility Levels 11

LIST OF ACRONYMS

ADT	Average daily traffic
AKDOT&PF	Alaska Department of Transportation and Public Facilities
CCD	Charged couple device
FHWA	Federal Highway Administration
MMA	Methylmethacrylate
MUTCD	Manual on Uniform Traffic Control Device
RRPMs	Raised retroreflective pavement markers
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
VL	Visibility Level
VOC	Volatile organic compound

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This research was performed in cooperation with the Alaska Department of Transportation and Public Facilities and the Federal Highway Administration. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Alaska Department of Transportation and Public Facilities or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ABSTRACT

This research determined the visibility of in-service pavement markings along lighted and unlighted highway sections, and compared visibility of in-service pavement markings to the FHWA proposed minimum retroreflectivity levels for the Alaska Department of Transportation and Public Facilities. In order to measure luminance in the field with a standard light source at a specific geometry, researchers custom built a specialized piece of data collection equipment, consisting of an industrial quality hand truck, a regulated switching power supply, a global positioning system receiver, a light source, a laptop computer, and a charged couple device photometer.

Researchers found that all of the pavement markings tested in this study would be in compliance with the Federal Highway Administration proposal. Continuous roadway lighting provided better visibility of pavement markings at longer distances than unlit highways. Along dark rural highways, the visibility of the raised retroreflective pavement markers and guardrail delineation tabs were greater than the pavement markings. All data collected in this project were under dry weather conditions.

SUMMARY OF FINDINGS

Researchers took photometric measurements at four specific distances of in-service pavement markings, RRPMs, and guardrail delineator tabs for roadways with and without lighting. The test sites measured were in compliance with the FHWA proposal for minimum pavement marking retroreflectivity levels. This includes the pavement markings from Dimond and Tudor that are 7 and 4 years old, respectively. These roadways have continuous roadway lighting and the pavement marking visibility along these roadways is equal to or greater than the minimum visibility requirements derived from the FHWA proposal. Other study sites that did not meet FHWA proposed minimum pavement marking retroreflectivity levels fell under the current exemptions based on roadway lighting, RRPMs, and volume thresholds.

Continuous roadway lighting provided better visibility of pavement markings at longer distances than unlit highways. Along dark rural highways, the visibility of the RRPMs and guardrail delineation tabs were greater than the pavement markings. This is impressive since the guardrail delineator tabs were about six years old, the RRPMs were about one year old, and the pavement markings were only one week old.

Given these conclusions, the authors recommend that the FHWA maintain the current exemptions to the minimum pavement markings retroreflectivity requirements as they move forward with rule-making. In addition, the FHWA should consider providing an exemption when guardrail delineation is provided. In this study, six year old guardrail delineation tabs provided equivalent visibility as one year old centerline RRPMs.

CHAPTER 1. INTRODUCTION

The Federal Highway Administration (FHWA) has started rule-making efforts to establish minimum maintained pavement markings retroreflectivity levels in the *Manual on Uniform Traffic Control Device* (MUTCD) (1,*2*). The proposed MUTCD language contains minimum pavement marking retroreflectivity levels that are based on vehicle speed and pavement marking configuration. There are also certain exemptions depending on roadway lighting presence, raised retroreflective marker presence and condition, and traffic volumes. The full proposed MUTCD language is posted on the MUTCD website at: http://mutcd.fhwa.dot.gov/knowledge/proposed09mutcdrev1/mutcd2009_pmretro.htm.

In northern climates, where winter maintenance activities such as snow plowing and snow removal are frequent, pavement marking retroreflectivity becomes difficult to maintain until the warmer and dryer weather of summer approaches (when road striping crews can start refurbishing the markings). In these areas, it is difficult enough to maintain pavement marking presence through the winter months, let alone retroreflectivity. Along continuously lit roadways, presence of the markings may provide adequate nighttime visibility. In Anchorage, many of the state maintained roadways are provided with continuous roadway lighting. Recessed retroreflective pavement markers are used on some unlighted rural roadways. An assessment of these practices is needed to determine their effectiveness in terms of providing adequate nighttime visibility as outlined in the MUTCD proposed language regarding minimum maintained pavement markings retroreflectivity levels.

Study Objectives

The key objectives of this research were to:

1. determine the visibility of in-service pavement markings along lighted highway sections;
2. determine the visibility of in-service pavement markings and recessed pavement markers along unlighted highways;
3. compare the visibility of in-service pavement markings to the FHWA proposed minimum retroreflectivity levels.

In addition, there was a secondary objective to assess the added visibility of the roadway where guardrail delineation is present.

Method

There are many different ways to quantify the visibility of pavement markings and other retroreflective delineation devices. While the most common is to rely on a retroreflected luminance value (more commonly referred to as retroreflectivity), the use of only retroreflectivity has many limitations. In fact, retroreflectivity is a property that is used for convenience more than anything since measuring the actual retroreflected luminance of traffic control devices in the field is difficult and time consuming, not to mention the safety concerns of having researchers on the roadway at night.

Pavement marking visibility, day or night, is a function of the contrast between the adjacent pavement surface and the marking. During the day, pavement markings with low retroreflectivity levels can be easily seen as long as they have a high contrast to the adjacent pavement surface. Even at night, pavement markings with low retroreflectivity levels can be visible, especially when roadway lighting is present.

For this research, efforts were made to provide a safe environment to make retroreflected luminance measurements of pavement markings and other delineation devices. Using specialized equipment, the team took luminance measurements of the traffic control devices of interest and their respective backgrounds. At some of the lighted roadways, measurements were made with the roadway lights on, and then again with the roadway lights off. The goal here was to assess visibility of in-service pavement markings with inadequate retroreflectivity levels (i.e., less than the FHWA proposed minimum levels) on roadways with lighting and to demonstrate the value of roadway lighting.

Using the target and background luminance measurements from the field, the team employed Adrian's Visibility Level (VL) model (3) to assess the visibility of the pavement markings, raised retroreflective pavement markers (RRPMs), and retroreflective guardrail delineation tabs. Adrian's model has been used as a way to assess the performance of roadway lighting (4) and as a way to assess pedestrian visibility (5). It has also been used in at least one previous study to assess pavement marking visibility (6).

In this study, VL was used as a measure of the visibility of the in-service pavement markings, RRPMs, and guardrail delineation. The VL model was derived from the landmark Blackwell studies in the 1940s and has been validated so much that the VL model now constitutes a reference to assess visibility. The VL computational model is described in a 1989 paper by Adrian (3). Higher VL scores are associated with more visible objects.

In laboratory situations, when observers know what to expect and have unlimited time for observation (2 seconds or more), a visibility level VL of one is sufficient to ensure detection of the target with a high probability. In traffic situations, on the other hand, there is not an unlimited amount of time for detection and detection is not always anticipated. Typically, a VL equal to 10 is recommended for traffic situations (3).

The advantage of using a visibility metric other than retroreflection is that comparisons can be made between the visibility of pavement markings, pavement markers, and guardrail delineation, and to assess the impact of roadway lighting. In addition, with pavement markings in the same condition as those used to derive the FHWA proposed minimum levels, the same visibility metric can be applied so that the visibility of in-service pavement markings, pavement markers, and guardrail delineation can be compared to the implied visibility set by the FHWA proposed minimum levels. So for this research, the benchmark VL when comparing in-service pavement markings is the derived VL from pavement markings in the same condition as those used to derive the FHWA proposed minimum levels. Such markings exist at the Texas Transportation Institute (TTI) and were used in this research to set benchmark VL to make comparisons against.

Working with the Alaska Department of Transportation and Public Facilities (AKDOT&PF), the researchers selected study sites consisting of roadways with and without lighting, as well as roadways with various features such as multilane, presence of RRPMs, presence of guardrail delineation, and with pavement markings of various condition (from worn to just applied). Lane closures were required for safety and they were coordinated with the AKDOT&PF along with Shaman Signs, a certified local traffic control company.

Before arriving to collect data, researchers built a specialized piece of data collection equipment to measure luminance in the field with a standard light source at a specific geometry. The equipment consisted of an industrial quality hand truck, a regulated switching power supply, a global positioning system receiver, a light source, a laptop computer, and a charged couple device (CCD) photometer. A picture of the data collection equipment being calibrated in the TTI Visibility Lab is shown in Figure 1.

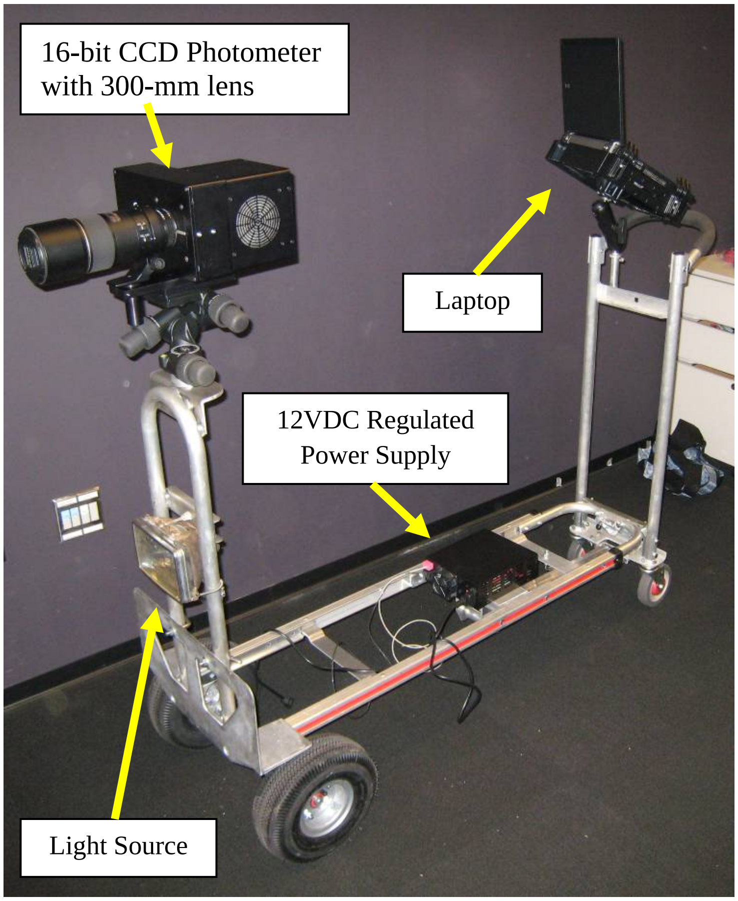

Figure 1. Data Collection Equipment.

The light source height was set to 0.65 m and the photometer height was set at 1.2 m. The light source was set at a standardized height representing a passenger car. A sealed beam tungsten-halogen headlamp operated at 12 VDC was used for the light source (and was photometrically measured to develop a luminous intensity matrix for modeling purposes). The photometer position represents a standard driver eye height. During field measurements, this equipment was located above the pavement marking. For safety reasons, the equipment was sometimes offset from the pavement marking to keep the researchers at a safe distance from passing traffic (less than 2 feet). At a distance of 30 m, the equipment produces an observation angle of 1.05 degrees and an entrance angle of 88.76 degrees, which corresponds to the standard geometry used to measure pavement marking retroreflectivity in accordance with ASTM E1710.

Study Sites

Selected roadways were chosen in the immediate Anchorage urban area as well as rural roadways near Anchorage. While safety was obviously a consideration in the site selection process, other factors were also important. For instance, the AKDOT&PF has made observations of pavement marking visibility along sections roadway with continuous roadway lighting and low pavement marking retroreflectivity levels (less than 25 mcd). As a result, study sites were also chosen so that the research team could make photometric measurements at such sites and document the visibility compared to the proposed FHWA minimum retroreflectivity levels. Photographs provided by the AKDOT&PF are shown in Figure 2 that demonstrate the experience of AKDOT&PF regarding the daytime and nighttime visibility of pavement markings with low retroreflectivity levels along roadways with continuous lighting.

Another aspect to the site selection process was capturing a range of pavement marking age (the length of time since the marking was last installed or refurbished). Sites were selected with pavement markings aging from 7 years old to approximately 7 days old.

On urban multilane roadways, the outside lane was closed and the lane lines were measured. Most of the rural highways were two-way two-lane highways so data collection focused on the edge lines. On Kodiak, where the nighttime volumes were less than 10 vph, measurements of the center lines were also taken. All of the sites were asphalt concrete pavement, tangent sections with constant grade except the second site in Kodiak, which was along a horizontal curve with constant grade. Table 1 shows a listing of each of the study sites and their characteristics.

Figure 2. Photographs of Dimond Blvd. in 2007 (4-year old in-laid MMA).

Table 1. Study Site Characteristics.

Roadway	Area	Road Class	Speed Limit	Traffic Volume	Study Area Description	Existing Pavement Marking Type and Age	Roadway Lighting	Measured Delineation
West Dimond Boulevard	Anchorage	Six Lane Arterial	45	30829	Between Minnesota Drive and Arctic Boulevard	In-laid 250 mil MMA, installed in 2003	Yes*	Lane line
Glenn Highway MP 5	Anchorage	Six Lane Freeway	65	53090	Between Arctic Valley and D St / Ft Rich Gate 2	In-laid 250 mil MMA, installed in 2010	Yes	Edge line
Glenn Highway MP 18	Anchorage	Four Lane Freeway	65	35790	Between South and North Birchwood Loop Road	In-laid 250 mil MMA, installed in 2010	No	Edge line
Rezanof Drive MP 2	Kodiak Island	Two Lane Minor Arterial	55	5314	Horizontal Curve near MP 2	Surface applied 60 mil MMA, installed in 2009, re-painted in 2010	No	Edge line, Center line, Center line RRPMs, Guardrail delineation
Rezanof Drive MP 9	Kodiak Island	Two Lane Minor Arterial	55	2219	MP 9 adjacent to the fairgrounds	Surface applied 60 mil MMA, installed in 2005, most recently re-painted in 2010	No	Edge line, Center line, Center line RRPMs
Minnesota Drive	Anchorage	Four Lane Freeway	60	23112	Between Raspberry Road and West Dimond Boulevard	In-laid 250 mil MMA, installed in 2009	Yes	Lane line
Seward Highway	Along Turnagain Arm	Two Lane Rural Arterial	55	8480	Between MP 97 and MP 99	Surface applied 60 mil MMA, installed in 2005, most recently re-painted in 2010	No	Edge line
TTI-150 TTI-50	TAMU Riverside Campus, TX	n/a	n/a	n/a	Markings from TxDOT's mobile retroreflectivity van calibration course at TTI	n/a	No	Calibration markings
East Tudor Road	Anchorage	Four Lane Arterial	50	29353	Between Boniface Parkway and Baxter Road	In-laid 125 mil MMA, installed in 2006	Yes*	Lane line

* At these sites, data were collected with roadway lighting on and then again with the roadway lighting off.

DATA COLLECTION

The measurements were taken during September 2010 between the hours of 10 PM and 3 AM on rainless nights. The pavement conditions for the measurements were dry. In any one night, one to two sites could be measured. Rain forced cancellations and ended data collection early during one night.

On each of the lighted roadways, measurements were taken at three equidistance locations spanning two consecutive overhead luminaires, while at the unlighted segments measurements were taken at one location. The purpose of having multiple locations along the lighted roadways was to be able to quantify the difference in lighting between consecutive luminaires.

For each location, luminance and illuminance data were collected at distances of 30, 44, 54, and 64 m from the data collection equipment. The 30 m data collection point was chosen to coincide with the standard measurement geometry of pavement marking retroreflectivity. The subsequent distances were chosen based on speeds of 45 mph, 55 mph, and 65 mph; and using 2.2 second time criterion, which is the same used in the FHWA minimum pavement marking retroreflectivity report (7).

At each location multiple CCD luminance measurements were taken to control for changes in lighting, such as the contributions from passing motorists. Two sets of illuminance readings were also recorded (with and without the standard light source on). For each set, the illuminance was measured in both a horizontal and vertical aspect to determine ambient lighting as well as the lighting provided by the standard light. The researchers also used a handheld pavement marking retroreflectometer to measure the pavement marking retroreflectivity. Daytime and nighttime digital photos were also taken. An image from the CCD luminance camera is shown in Figure 3. Targets were set at the predetermined distances to facilitate data reduction from the images. Each target represents a distance of 30, 44, 54, and 64 m.

The researchers used the same equipment and protocol to measure pavement markings on the TxDOT mobile retroreflectivity calibration course at the Texas A&M University Riverside Campus. There are nearly 50 different 0.5 mile long pavement markings on the TxDOT mobile retroreflectivity calibration course with various characteristics. Luminance measurements were made on pavement markings of 50 mcd and 150 mcd were chosen based on the FHWA proposed minimum retroreflectivity levels. The pavement type at the Riverside Campus is concrete.

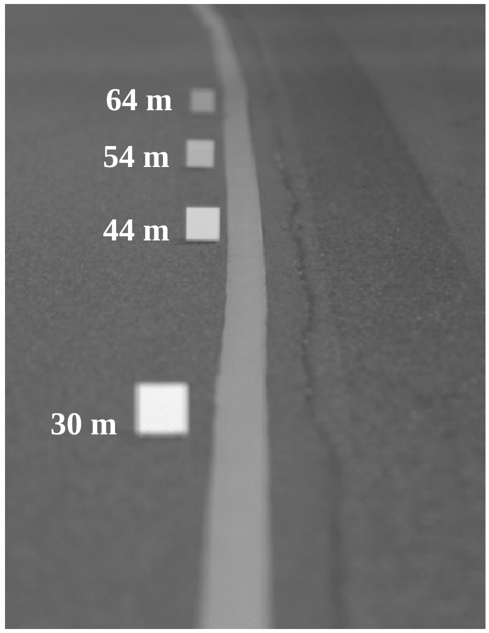

Figure 3. Typical CCD Image for 44m Measurements.

CHAPTER 2. RESULTS

The results of this research are divided into two sections. The first section describes the results from comparing the measured pavement marking visibility to the implied pavement marking visibility derived from the FHWA proposed minimum pavement marking retroreflectivity levels. The second section describes the relative visibility of the center line RRPMs and guardrail delineators in terms of the pavement markings along the same section.

Pavement Marking Visibility

The pavement marking retroreflectivity was measured along each roadway (in September 2010). The measured values and the FHWA proposed minimum retroreflectivity levels are shown in Table 2.

Table 2. Comparison of Measured and Proposed Minimum Retroreflectivity Levels.

Roadway/Pavement Marking	FHWA Proposed Minimum Retroreflectivity Level	Measured In-Service Retroreflectivity Level	Approximate Date of Most Recent Striping
Dimond*/Lane Line	50	14	Summer 2003
Glenn Hwy* MP 5/Edge Line	100	260	Summer 2010
Glenn Hwy MP 18/Edge Line	100	220	Summer 2010
Kodiak MP 2/Edge Line	100	110	Summer 2010***
Kodiak MP 2**/Center Line	100	80	Summer 2010***
Kodiak MP 9/Edge Line	n/a	not measured	Summer 2010***
Kodiak MP 9**/Center Line	n/a	not measured	Summer 2010***
Minnesota*/Lane Line	100	72	Summer 2009
Seward /Edge Line	100	296	Summer 2010
Tudor*/Lane Line	50	50	Summer 2006

* These sites have continuous roadway lighting and would be exempt from the FHWA proposed minimum pavement marking retroreflectivity levels.
** This site has center line RRPMs and could be exempt from the FHWA proposed minimum pavement marking retroreflectivity levels if three were visible.
*** Striping crews were onsite and had completed these test sites within one week of this project.

The study sites with pavement marking retroreflectivity levels below the FHWA proposed minimum levels had either roadway lighting or RRPMs that have the potential to provide relief from the FHWA proposed minimum levels (if adopted as proposed in the NPA). The pavement marking retroreflectivity levels on Kodiak are noticeably low given that they were recently restriped before the measurements were taken. One reason for this could have been the 2010 world-wide shortage of raw materials for pavement markings. Agencies across the country handled the shortage in different ways. In Alaska, the relaxed practices resulted in approximately 10 mil paint applications. In addition, Kodiak Island is almost always damp and wet. These conditions may explain why the new markings on Kodiak had relatively low retroreflectivity levels. Despite the low retroreflectivity measurements on Kodiak, it is worth noting the all of the recently placed pavement markings in Alaska were in compliance with the FHWA proposed minimum retroreflectivity levels.

As an additional note, different sections of Rezanof Drive on Kodiak would be exempt based on their traffic volume. The FHWA proposed minimum retroreflectivity levels would apply to longitudinal markings that are either required or recommended by the MUTCD. For center line and edge line markings of Rezanof Drive on Kodiak, the threshold volume is 3000 ADT. The ADT at along Rezanof Drive at MP9 was only 2219. Therefore, because of these lower traffic volumes, this location of Rezanof Drive would not be subject to the FHWA proposed minimum retroreflectivity levels.

In order to determine how lighting contributes to the visibility of pavement markings, the researchers computed the visibility level of the pavement markings at four distances. At two of the study sites (along Dimond and along Tudor), measurements of the pavement markings were made with and without the overhead lighting. In addition, on the Glenn Highway, measurements of the pavement markings of the same type and age were made in nearby sections—one with roadway lighting and one without roadway lighting. In order to set a baseline visibility criterion that reflects FHWA proposed minimum retroreflectivity levels, measurements of pavement markings were made at TTI and are subsequently referred to at TTI-150 and TTI-50. These terms describe clean and dry pavement markings in dark rural areas along straight and flat sections of roadway with retroreflection levels of 150 and 50 mcd, respectively (i.e., the conditions under which FHWA used to establish their proposed minimum retroreflectivity levels).

For each study site, Table 3 shows the measured retroreflectivity and the VL at each of the four study distances. For lighted roadways, readings were taken at three equidistance locations spanning two consecutive luminaires and then averaged.

Table 3. Pavement Marking Visibility Levels.

Roadway	Lighting Condition	Pavement Marking	Measured R_L	Computed Visibility Level (VL)			
				30 m	44 m	54 m	64 m
Dimond	Dark	Lane Line	14	19	*	6	5
Dimond	Lit	Lane Line	14	57	46	32	22
Glenn MP18	Dark	Edge Line	220	32	16	10	9
Glenn MP 5	Lit	Edge Line	260	33	15	12	12
Kodiak MP 9	Dark	Edge Line	not measured	26	14	7	4
Kodiak MP 2	Dark	Edge Line	110	93	46	30	19
Minnesota	Lit	Lane Line	72	19	13	9	7
Seward	Dark	Edge Line	296	55	31	19	10
TTI	Dark	Edge Line	150	27	13	7	4
TTI**	Dark	Edge Line	100	22	10	5	3
TTI	Dark	Edge Line	50	17	7	3	2
Tudor	Dark	Lane Line	50	24	14	5	4
Tudor	Lit	Lane Line	50	23	16	11	9

* The data in this cell were deemed implausible and were not used.
** Computed from the VL values from the TTI 150 and TTI 50 sites.

The advantage of using a visibility metric here is that comparison can be made between the visibility of pavement markings with various roadway surface types, lighting, and retroreflectivity. For this study, the markings measured at TTI provide benchmark VL values to make comparisons. In Figure 4, the horizontal dashed lines represent the VL of pavement markings of 100 and 50 mcd on unlit roadways at a distance of 44 m. Again, the distance of 44 m is based on a speed of 45 mph and a 2.2 second time criterion. The data collected at the Dimond site for 44 m resulted in unrealistic VL levels that were discarded.

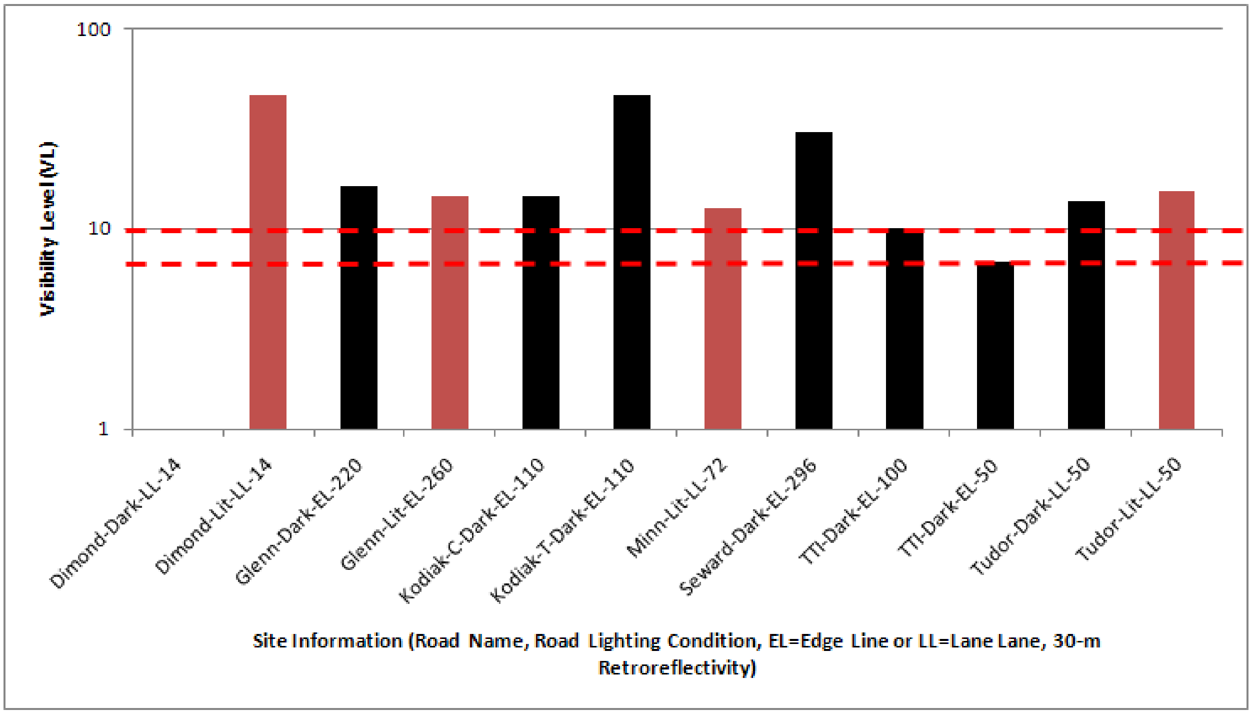

Figure 4. Pavement Marking Visibility Levels at 44 Meters.

In Figure 4, the VL is shown in the y-axis and the study sites are shown on the x-axis. The VL of sites without roadway lighting is shown with black bars. The dashed lines represent the implied visibility of the FHWA proposed minimum retroreflectivity levels at a distance of 44 m (see the bars labeled TTI-Dark-EL-100 and TTI-Dark-EL-50). Again, all of the pavement markings at the study sites provide as much visibility as implied by the FHWA proposed minimum retroreflectivity levels at a distance of 44 m.

The differences in pavement marking visibility between the lit and unlit sections of the Glenn Highway were quite small. The same goes for Tudor Road. At this distance, the study sites with lighting provided as much visibility without the lighting as they did with the lighting (AKDOT&PF illumination specifications call for 400 Watt High-Pressure Sodium lighting with medium cutoff fixtures. Spacing ranged from 300 to 400 ft). It should be noted, however, that the VL values can vary significantly depending on where the measurements are made with respect to the roadway lighting luminaires. A data collection protocol was established and implemented using readings from three equidistance locations spanning two consecutive luminaires. Figure 5 is similar to Figure 4 except it represents the visibility of the pavement markings at 54 m instead of 44 m. The 54 m was derived from a speed of 55 mph with 2.2 seconds.

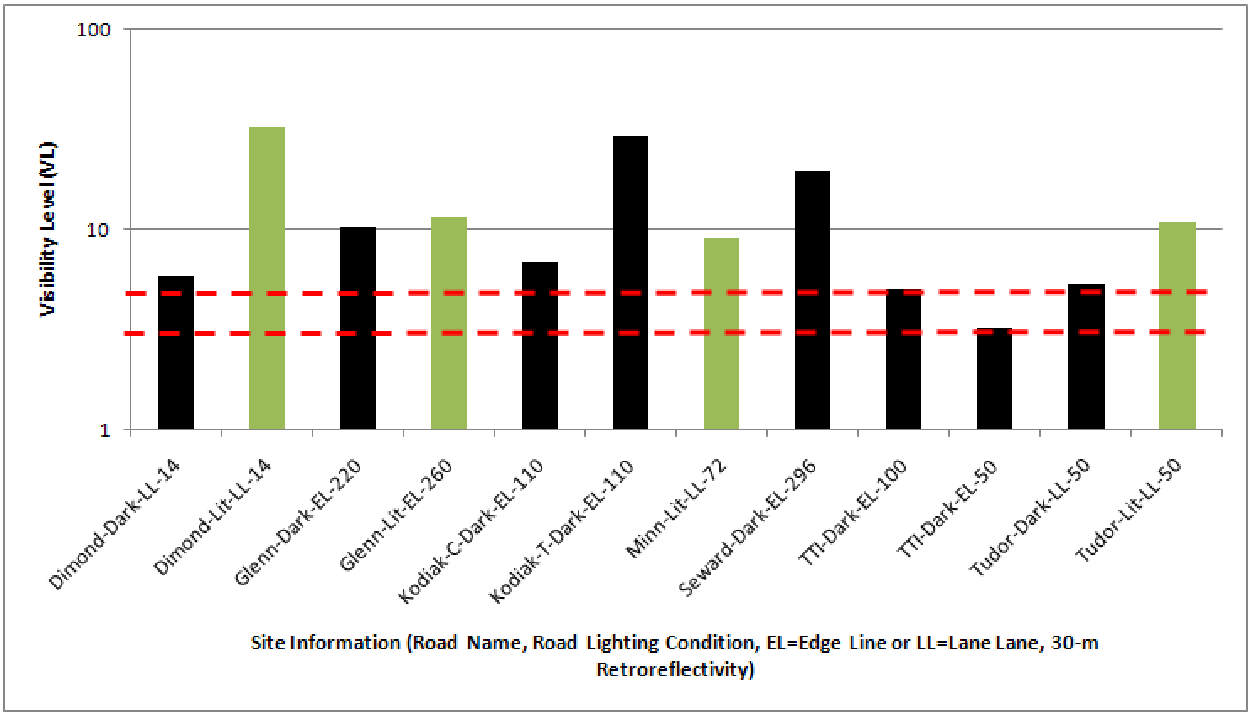

Figure 5. Pavement Marking Visibility Levels at 54 Meters.

As before, Figure 5 also shows that all of the pavement markings at the study sites provide as much visibility as implied by the FHWA proposed minimum retroreflectivity levels, but this time at a distance of 54 m. The differences in pavement marking visibility between the lit and unlit sections of Dimond and Tudor are more prominent at this distance and demonstrate the value of roadway lighting. For the Glenn Highway, the differences are smaller but these measurements were not made at the same location as the Dimond and Tudor measurements so there could be other influences.

Figure 6 is the third and final graph in this set but this time representing the farthest distance of 64 m, which is based on a speed of 65 mph. These results tell a familiar story—the pavement markings at the study sites provide as much visibility as implied by the FHWA proposed minimum retroreflectivity levels at 64 m. The differences in pavement marking visibility between the lit and unlit sections of Dimond and Tudor are prominent at this distance and demonstrate the value of roadway lighting. For the Glenn Highway, the differences are smaller but these measurements were not made at the same location as the Dimond and Tudor measurements so there could be other influences.

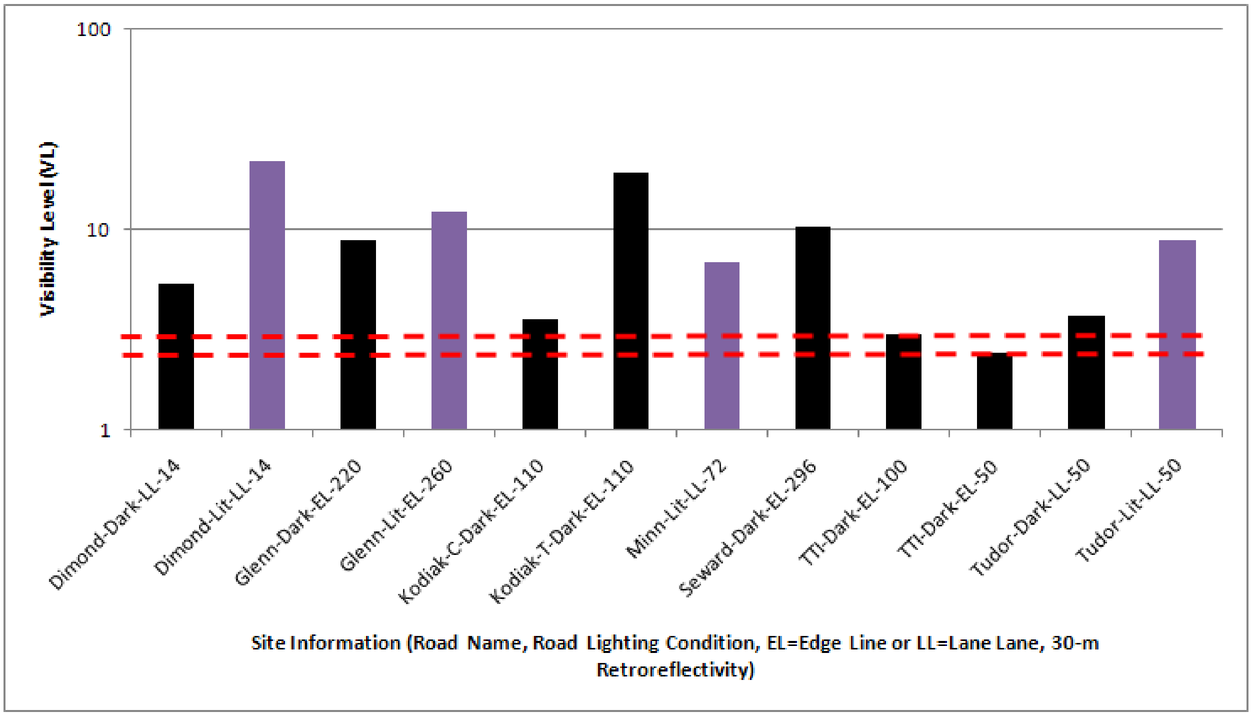

Figure 6. Pavement Marking Visibility Levels at 64 Meters.

RRPM and Guardrail Delineator Visibility

In order to understand how RRPMs and other types of delineation may assist nighttime drivers, measurements of nonplowable retroreflective raised pavement markers and retroreflective guardrail delineator tabs (the type bolted into the valley of a W-beam guardrail) were also made along Rezanof Drive on Kodiak Island. Figure 7 shows the VL values for the edge line, center line, and center line RRPMs for the tangent site on Kodiak (MP 9 of Rezanof Drive).

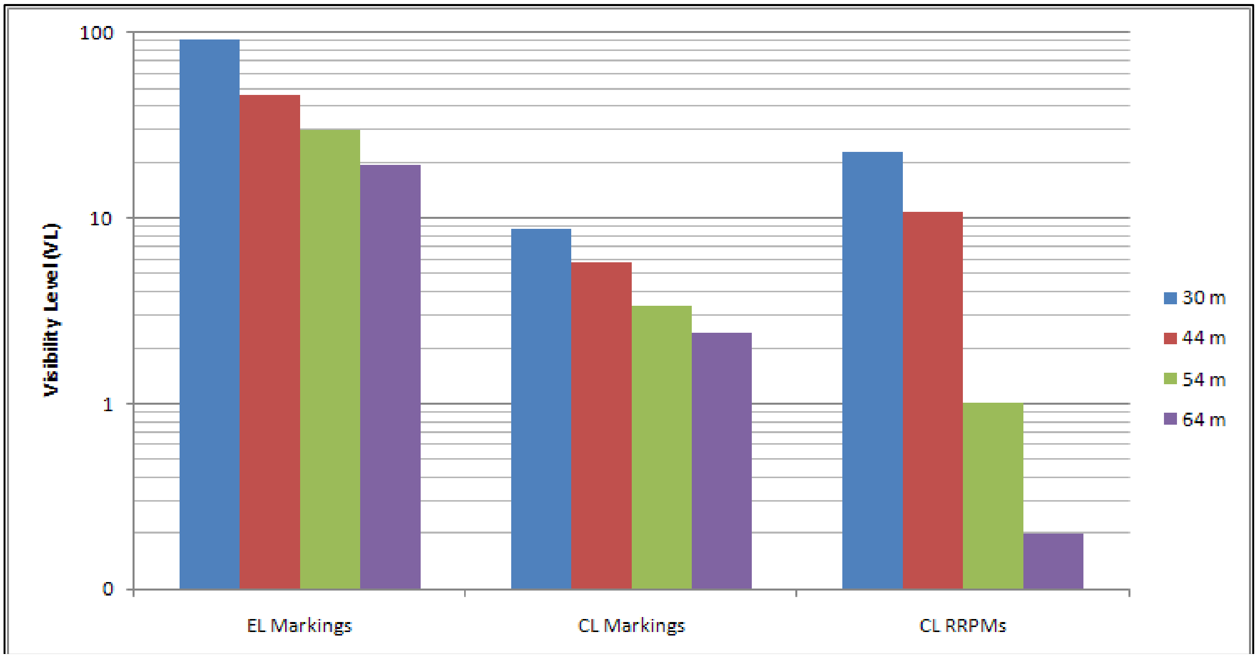

Figure 7. Visibility Levels of Delineation Treatments at MP9 on Rezanof Drive.

Figure 7 shows some interesting results regarding the visibility of the markings and center line RRPMs. First, the overall VL for the markings is relatively high given the measured retroreflectivity (110 mcd on the edge line and 80 mcd on the center line). This section of roadway was paved in 2005 and the asphalt has become polished, which typically leads to low measurements of returned pavement surface luminance. This can lead to a higher contrast and therefore higher VL levels (versus the same retroreflective markings on a road surface returning higher luminance levels). Second, the center line markings provide the same VL trend as the edge line markings except that they are at a noticeably reduced level. These lower VL are a function of two factors working in tandem—the yellow center line markings have lower retroreflectivity levels than the white edge line markings (80 versus 110), and the reduced headlamp illumination reaching center line markings compared to edge line markings.

When the site was repaved in 2005, the original markings were installed using methylmethacrylate (MMA). They were refurbished with low VOC paint and AASHTO Type I beads approximately one week before they were measured for this paper. The center line RRPMs were installed in 2005 when the road was resurfaced (see Figure 8). They were nonplowable retroreflective raised pavement markers and they were installed in a groove about 0.5 inch deep (AKDOT&PF specified depth is 0.375 inch). Subjectively speaking, the nighttime visibility of the RRPMs along this site was marginal. During night drives through this site, it was common to see two consecutive RRPMs but seeing RRPMs beyond two in view at any one time was uncommon. From visual observations made while driving this site at night, a VL of 1 or less would be almost undetectable and therefore unacceptable (the VL of the CL RRPMs at 54 and 64 m are less than or equal to 1). The photometric equipment used in this study is capable of measuring RRPMs at distances beyond what the human eye can see. The results in Figure 7 seem to coincide as the RRPM visibility measured with VL is greater than or equal to 10 for the 30 and 44 m distances but much less for the longer distances (less than or equal to one).

During the restriping of this section the RRPMs were partially covered with overspray paint (see Figure 9). The maintenance restriping was placed in accordance with standards for typical double yellow lines using a 3-inch gap. However, AKDOT&PF standard drawings call for increasing this gap when using RRPMs, which would have been done when the original RRPMs were placed. In addition, it is also possible that the grooves for the RRPMs were not deep enough along this section to protect them (these measurements were not recorded in the field).

Figure 8. Original RRPM Placement on Rezanof Dr. (circa 2005).

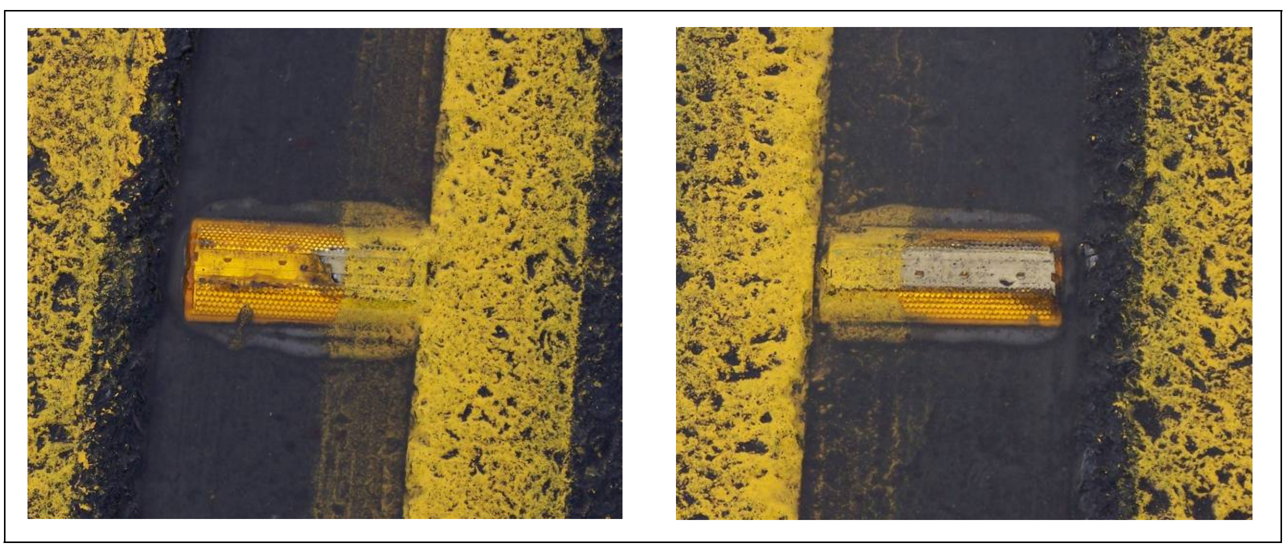

Figure 9. Images of Center Line RRPMs after Restriping with Paint.

Figure 10 shows the VL values for the edge line markings, center line markings, center line RRPMs, and guardrail delineator tabs along the second site on Kodiak (MP2 on Rezanof Drive), which happened to be a horizontal curve. The pavement markings at this site were refreshed within one week prior to our measurements. The RRPMs were installed in 2009, when the site was resurfaced. The guardrail delineation tabs were installed in 2004.

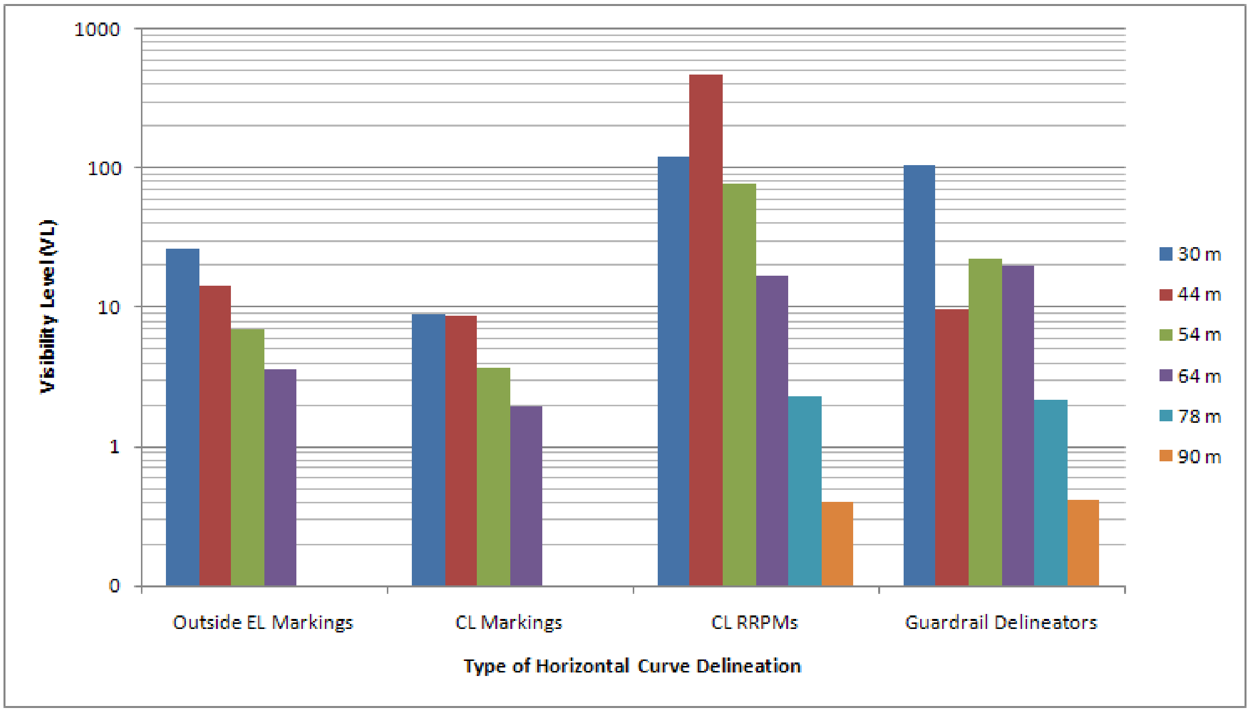

Figure 10. Visibility Levels of Delineation Treatments at MP2 on Rezanof.

Figure 10 shows the same trends in the pavement markings as noted previously except with a lower overall VL. The markings were just applied within the week prior to the measurements using low VOC paint and Type I AASHTO M247 beads. The RRPMs were nonplowable retroreflective raised pavement markers and they were installed in a 0.5 inch deep groove as per the contract specification. The guardrail delineator tabs were the butterfly variety and they were installed in 2004.

At this site, which is only about 7 miles from the first Kodiak site (shown in Figure 7), the center line RRPMs performed much better despite being in a horizontal curve. However, these RRPMs were only one year old versus five years old at the first Kodiak site. Again, even though a sixth RRPM is shown in the graph (with a VL < 1), it was not possible to detect this RRPM at night. For distances out to 64 m, the center line RRPMs provide about double the visibility of the center line markings.

The guardrail along this curve ran concentric with the curve and was offset approximately 8 feet from the edge line. Inside the W-beam were guardrail delineator tabs installed in 2004. The second guardrail delineator was noticeably damaged and the VL for that delineator shows it. Overall though, the guardrail delineation here provides greater visibility than the edge line markings, at least out to 64 m. The sixth guardrail delineator is shown in Figure 10 but could not be seen by the eye at night. Daytime and CCD images from this site are shown in Figure 11.

Figure 11. Images from MP2 on Rezanof Drive on Kodiak.

CHAPTER 3. SUMMARY

For this research, photometric measurements were taken of in-service pavement markings, RRPMs, and guardrail delineator tabs. The study sites included roadways with and without roadway lighting. The photometric measurements were used to compute visibility levels of the retroreflective devices at four specific distances. The visibility levels of the in-service pavement markings were compared to the implied visibility level of the FHWA proposed minimum pavement marking retroreflectivity levels. The visibility level of the RRPMs and guardrail delineation was also compared to the visibility level of the pavement markings at the same sites.

The measured retroreflectivity levels of the in-service markings were compared to the FHWA proposed minimum pavement marking retroreflectivity levels and it was found that all of the pavement markings would be in compliance with the FHWA proposal. The sites that would have been in jeopardy of failing the FHWA proposed minimum pavement marking retroreflectivity levels fell under exemptions based on roadway lighting, RRPMs, and volume thresholds for longitudinal markings.

The visibility of the pavement markings along lit sections of roadway was as great or greater than the implied minimum visibility of pavement markings as derived from the FHWA proposed minimum pavement marking retroreflectivity levels. The benefit of the roadway lighting was most evident at the longer distances tested (54 and 64 m).

The visibility of center line RRPMs along the unlit rural roadways was greater than the center line pavement markings but varied depending on the condition (i.e., age) of the RRPMs. In one case, where the age of the RRPMs was about five years, the visibility of the RRPMs was considered marginal. On another section of the same road where the RRPMs were only about one year old, the visibility of the RRPMs was significantly greater than the pavement markings. Of course the photometric measurements were all taken under dry conditions and therefore the benefits of RRPMs in wet conditions was not assessed (more on this later).

For the one site that had guardrail delineation, the visibility of the guardrail delineation was greater than the edge line markings. In fact, the visibility of the guardrail delineation was nearly equivalent to the visibility of the center line RRPMs at the same site. This is impressive since the guardrail delineator tabs were about six years old and the RRPMs were about one year old. Finally, like the RRPMs, perhaps the greatest benefit provided by the guardrail delineation would be in wet conditions, which were not assessed in this research.

Concluding Remarks

All of the pavement markings measured would be in compliance with the FHWA proposed minimum retroreflectivity levels. This includes the pavement markings from Dimond and Tudor that are 7 and 4 years old, respectively. These roadways have continuous roadway lighting and the pavement marking visibility along these roadways is equal to or greater than the minimum visibility requirements derived from the FHWA proposed minimum retroreflectivity levels (despite having quite low retroreflectivity levels). Other study sites that did not meet FHWA proposed minimum pavement marking retroreflectivity levels fell under the current exemptions based on roadway lighting, RRPMs, and volume thresholds. Continuous roadway lighting provided better visibility of pavement markings at longer distances than unlit highways. Along dark rural highways, the visibility of the RRPMs and guardrail delineation tabs were greater than the pavement markings.

Given these conclusions, the authors recommend that the FHWA maintain the current exemptions to the minimum pavement markings retroreflectivity requirements as they move forward with rule-making. In addition, the FHWA should consider providing an exemption when guardrail delineation is provided. In this study, six year old guardrail delineation tabs provided equivalent visibility as one year old centerline RRPMs.

For the AKDOT&PF, there is some evidence to help make strategic decisions regarding pavement marking restriping policies. Areas with continuous roadway lighting appear to have more than adequate visibility despite having low retroreflectivity levels. As long as pavement markings presence can be maintained on these roadways, the agency may be able to extend their restriping policies on these roadways allowing them to get to more rural unlit roadways. In addition, on the rural unlit highways, the AKDOT&PF may want to consider a life cycle cost analysis considering conventional and durable pavement markings, RRPMs, and roadside delineation.

Wet Conditions

As described earlier, all of the measurements made and described in this paper represent dry conditions. It is well known that most conventional pavement markings lose considerable nighttime visibility performance in wet conditions. Thus, in some sense, it is not fair to only consider the benefits of RRPMs and guardrail delineation tabs during dry nighttime conditions. Immediately following data collection on Kodiak, the AKDOT&PF observed and filmed the Rezanof Drive under nighttime rain conditions. These observations showed that the pavement markings were even less visible than expected. However, the recorded nighttime drives clearly show that the RRPM visibility was much better than the pavement markings, even for the five year old RRPMs. The observations also showed that the guardrail delineation tabs were the most visible delineation treatment, even compared to the one year old RRPMs. An AKDOT&PF conclusion is that guardrail delineation tabs provide superior visibility as compared to pavement markings in wet conditions. Part of the reason is the vertical surface. Another reason is that the guardrail delineation tabs are not exposed to tire hits like pavement markings and pavement markers. While they can become quite dirty, the six year dirt build-up on those measured in this study shows that they can still provide high levels of visibility.

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