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The Assessment of Alternative Overhead Sign Lighting

Brian Williams, Ron Gibbons

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Technology
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Housed at the Virginia Tech Transportation Institute
3500 Transportation Research Plaza • Blacksburg, Virginia 24061

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	analysis of variance
DAS	data acquisition system
DMX	digital multiplex signal
HPS	high-pressure sodium
KWh	kilowatt hour
SNK	Student-Newman-Keuls
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

BACKGROUND

Effective use of highway guide signs is critical in supporting driver decision-making and increasing driver comfort and safety. Therefore, it is important to make sure that guide signs are clearly visible in both daytime and nighttime conditions. The use of retroreflective material has proven to greatly enhance the visibility of guide signs in nighttime conditions to the point that an approaching vehicle's headlamps provide sufficient illumination, and sign lighting is not needed in many cases.

Previous research has shown, however, that in areas with high visual complexity, lighting is still needed to provide adequate guide sign visibility. Traditional means of lighting guide signs include mounting luminaires directly above or below the sign. Each method has advantages and disadvantages. Luminaires mounted above a sign reduce the amount of light pollution above the sign, while luminaires mounted below the sign reduce the risk of presenting glare to drivers below the sign. A disadvantage of both methods is that the luminaires are often so close to the sign that the majority of light is concentrated in one area, creating a "hot spot" on the sign. To remedy this, signs are often illuminated by two or more luminaires in order to achieve the necessary uniformity of light.

Additionally, lighting a sign from directly above or below does not take advantage of the sign's retroreflective properties. The retroreflective nature of the sign means that most of the light emitted by a luminaire is reflected back toward the luminaire, and not toward an approaching driver. When using lights above and below, the light is instead reflected back up toward the sky, or down toward the roadway, rather than toward the sign, depending on the method being used.

In the face of these drawbacks, the research team proposed an alternative method for lighting signs, which might take advantage of their retroreflective properties, thereby reducing the amount of light and number of luminaires needed to provide adequate sign visibility. This alternative sign lighting would utilize a single luminaire mounted some distance upstream of the sign, with a focused, but evenly distributed beam. The goal was to mimic the way in which a vehicle's headlamps illuminate a sign, but at a fixed distance so that the sign always receives the same amount of illumination.

PROJECT APPROACH

The purpose of this project was to evaluate the effectiveness of an alternative method of lighting overhead guide signs. A human-subjects study was conducted in which participants observed two guide signs under different lighting configurations and read aloud two words displayed on each sign as soon as they became legible. The distance at which participants could read a sign, termed the legibility distance, was compared across lighting conditions.

LITERATURE REVIEW

Carlson and Hawkins examined the effects of luminance on the legibility distance of overhead guide signs by varying the luminous intensity of a test vehicle's headlamps (Carlson & Hawkins, 2003). Participants read signs at distances corresponding to specific legibility indices. The results of this study were used in the development of overhead sign retroreflectivity requirements. The requirement to provide a minimum luminance of 2.3 cd/m^2 is based on the minimum luminance needed in order for one half of elderly drivers to have a 40-ft/in. legibility index.

A study by Holick and Carlson examined the luminance needed for sign legibility in more visually complex scenarios. While this research, like the previous one, was done in a rural setting, it included factors such as roadway lighting and headlight glare (Holick & Carlson, 2008). The presence of glare doubled the amount of luminance needed for the sign to be clearly legible. When roadway lighting was added to the glare condition, it offset some of the impact of the glare. In this scenario, the same legibility was achieved with only 15% more luminance.

The previous findings indicate that the legibility distance of a sign can be increased by increasing the sign luminance. However, both of these studies were performed in dark rural settings with low visual complexity and a low mental workload for drivers. Carlson, Brimley, Miles, Chrysler, Gibbons, and Terry (2016) performed a study which examined the relationship of luminance and sign legibility under various levels of visual complexity. Levels of visual complexity were quantified using a scale of 1 through 5, where 1 represented “very rural areas,” and 5 represented “the most visually complex sign surroundings.” Results of the research found a linear relationship where, for every unit increase in visual complexity, an increase in luminance of 5.6 cd/m^2 was needed to achieve similar legibility.

Figure 1. Photos. Examples of low (left) and high (right) visual complexity (Carlson et al., 2016).

A key finding from the study was that, due to the retroreflective sheeting used to make guide signs, illuminance is a poor predictor of legibility because it provides no indication of sign luminance from the driver’s perspective (Carlson et al., 2016). The current study sought to examine an alternative form of sign lighting which uses the sign’s retroreflective properties to provide increased luminance to the driver, even when providing less illuminance to the sign.

CHAPTER 2. EXPERIMENTAL DESIGN

A human-subjects experiment was conducted on the Virginia Smart Road at the Virginia Tech Transportation Institute (VTTI). The study examined the legibility of guide signs under different lighting conditions. Two sign configurations were used. The "overhead" sign was mounted on a sign gantry above the roadway, and directly above the lane in which participants drove. The "curve" sign was mounted to the side of the roadway in a curve. The purpose of the overhead sign was to examine sign visibility in a scenario that most closely matched the way signs are encountered in highway driving. The curve sign was added in order to determine if the alternative form of sign lighting might help in other scenarios, such as signs mounted near horizontal curves in which a driver's headlights may not fall directly on the sign. Each scenario was analyzed separately, with each having a 2 (Age) × 3 (Sign Lighting) × 2 (Luminance) mixed-factors design. Table 1 lists each of the factor levels for each sign scenario.

Table 1. Sign scenario factor levels.

Sign	Age	Sign Lighting	Luminance
Overhead	Younger	Overhead	High
	Older	Guardrail	Low
		Headlamps	
Curve	Younger	Near	High
	Older	Far	Low
		Headlamps	

INDEPENDENT VARIABLES

Several variables were manipulated or controlled during the study, as listed below.

Between-Subjects Variables

- **Gender** (2 levels): Female, Male. This variable was chosen in order to generalize the results to a broad driver population and was not used in the analysis.

- **Age** (2 levels): Younger (18–34), Older (60+). Two age groups were selected to study the differences in behavior and perception between younger and older drivers. Older drivers typically have more experience, while younger drivers typically have better vision.

Within-Subjects Variables

- **Luminance** (2 levels): Low, High. This variable was chosen to determine how the intensity of the sign lighting affects sign legibility.

- **Overhead Sign Lighting** (3 levels): Overhead, Guardrail, Headlamps-only. This variable was chosen to examine different positions for the overhead sign luminaire, as well as to provide a comparison to a headlamp-only condition.

- **Curve Sign Lighting** (3 levels): Near, Far, Headlamps-only. This variable was chosen to examine different positions for the luminaire in the curve sign scenario, as well as to provide a comparison to a headlamp-only condition.

DEPENDENT VARIABLES

Two different dependent variables were used for the overhead and curve signs, as follows:

- **Legibility Distance**: The distance at which a participant was able to correctly read two words on the overhead sign. A participant read aloud two words displayed on the sign as soon as they were legible. At this moment, an in-vehicle experimenter would flag the data stream by pressing a handheld button. Later analysis determined the distance between this location and the sign by using the vehicle's GPS coordinates.

- **Legibility Angle**: The angle at which a participant was able to correctly read the two words on the curve sign. Due to the curve of the road in this scenario, it did not make sense to calculate a straight line distance. Rather, the angle of the participant vehicle with regard to the sign was calculated.

EQUIPMENT AND FACILITIES

Smart Road

The experiment was conducted on the Virginia Smart Road. The Smart Road is a 2.2 mile-long, 2-lane restricted-access road. The Smart Road is equipped with an overhead sign gantry located in a straight segment near the middle of the roadway. The overhead sign was mounted here, above the uphill driving lane. The curve sign was mounted off the roadway in the upper turnaround. These locations are illustrated in Figure 2.

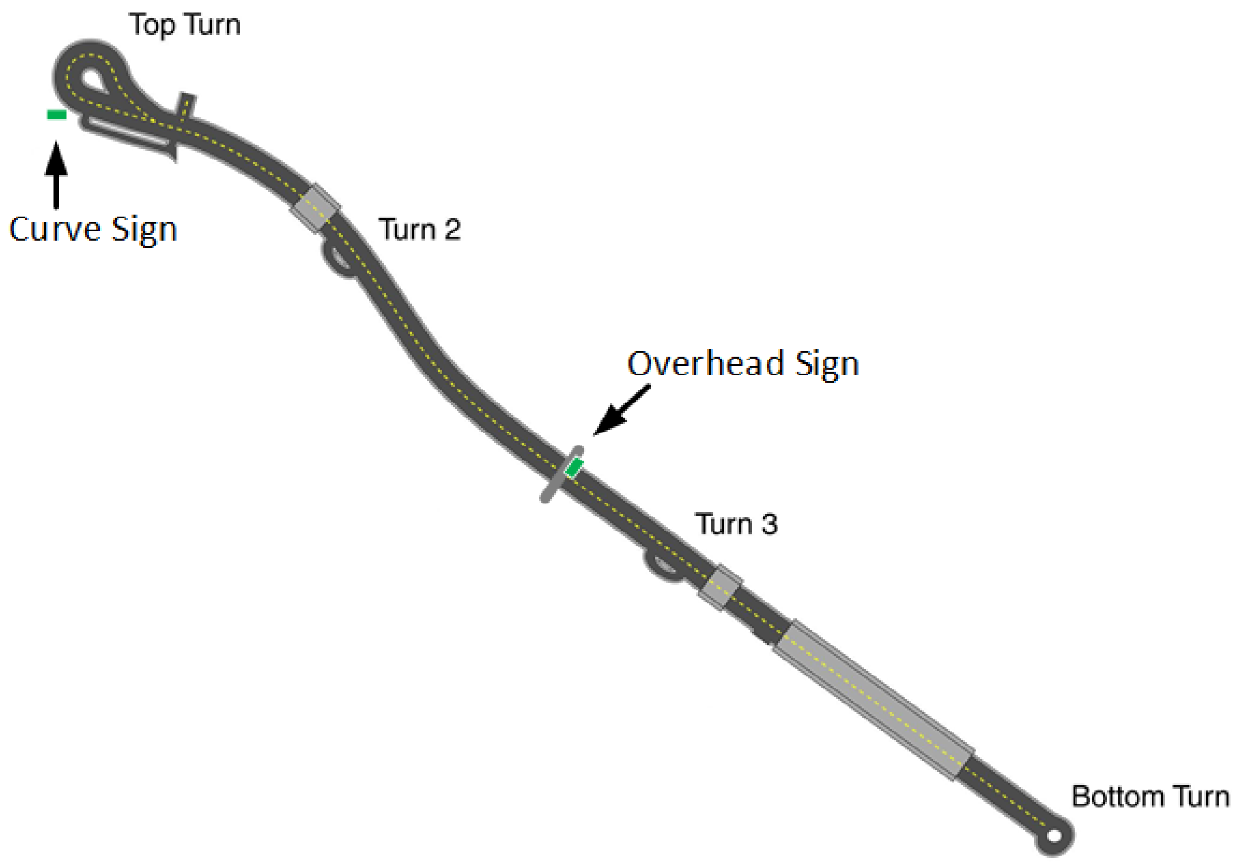

Figure 2. Illustration. Sign locations on the Virginia Smart Road.

The positioning of the curve sign was intended to mimic a scenario in which a side-of-the-road guide sign is mounted near the end of an entrance ramp. Figure 3 shows a diagram of the curve sign scenario as it was set up on the Smart Road (left), and the hypothetical entrance ramp scenario it was meant to mimic (right). The black rectangle and blue triangle represent the luminaire and its light beam, respectively. The dashed blue line represents the retroreflected light of the luminaire that reaches the participant.

Figure 3. Illustration. Curve sign scenario: actual (left), and hypothetical (right).

Test Vehicles

The experiment used two Ford Explorers (model years 1999 and 2000), each equipped with a data acquisition system (DAS). The DAS recorded camera views inside and outside the vehicle, as well as vehicle speed, GPS location, and other data from the vehicle's network. Both vehicles used low-beam halogen headlamps on a custom-built mounting system. The headlamps were mounted at the same height and width for each vehicle and were aimed prior to each session.

Signs

Both signs used in the study were 8 ft × 12 ft and used a white legend on a green background. The overhead sign consisted of a Type IV prismatic legend on a Type III beaded background (Figure 4). The curve sign consisted of a Type XI prismatic legend on a Type IV prismatic background (Figure 5). The legend was a Clearview 5 WR font and used mixed-case letters with an uppercase letter height of 16 in.

Figure 4. Photo. Close-up of overhead sign and legend material.

Figure 5. Photo. Close-up of curve sign and legend material.

Luminaires

Due to the unconventional nature of the alternative lighting method, there were no off-the-shelf luminaires designed for lighting roadway signs in this manner. Instead, the study utilized theater spotlights. Specifically, three Chauvet DJ EVE E-100Z luminaires were used to achieve the different lighting conditions (Figure 6). These luminaires provided a directional beam with framing shutters that allowed for precise lighting of the signs from a distance. A digital multiplex (DMX) signal controller was used to activate and deactivate the luminaires and to set the dim levels when appropriate. Dim settings were achieved using a slider on the DMX controller. Two settings were used: high (100% output) and low (~13% output).

Figure 6. Photo. Chauvet DJ EVE E-100Z luminaire.

Overhead Sign Lighting Conditions

For the overhead sign, the luminaires were mounted onto a collapsible gantry approximately 20 m upstream of the sign gantry. The luminaires were positioned in two locations on the collapsible gantry (Figure 7), as follows:

- **Overhead –** The luminaire was mounted from the collapsible gantry arm at approximately 6 m high, and just inside the driving lane. This location was used in order to get the luminaire as close to the driving lane as possible, with the goal of increasing the amount of retroreflected light that would be directed toward the drivers.

- **Guardrail –** The luminaire was mounted just behind the guardrail at a height of approximately 2 m. This location was used to investigate how well the lighting method would work from a position that would be more practical from a mounting and maintenance perspective.

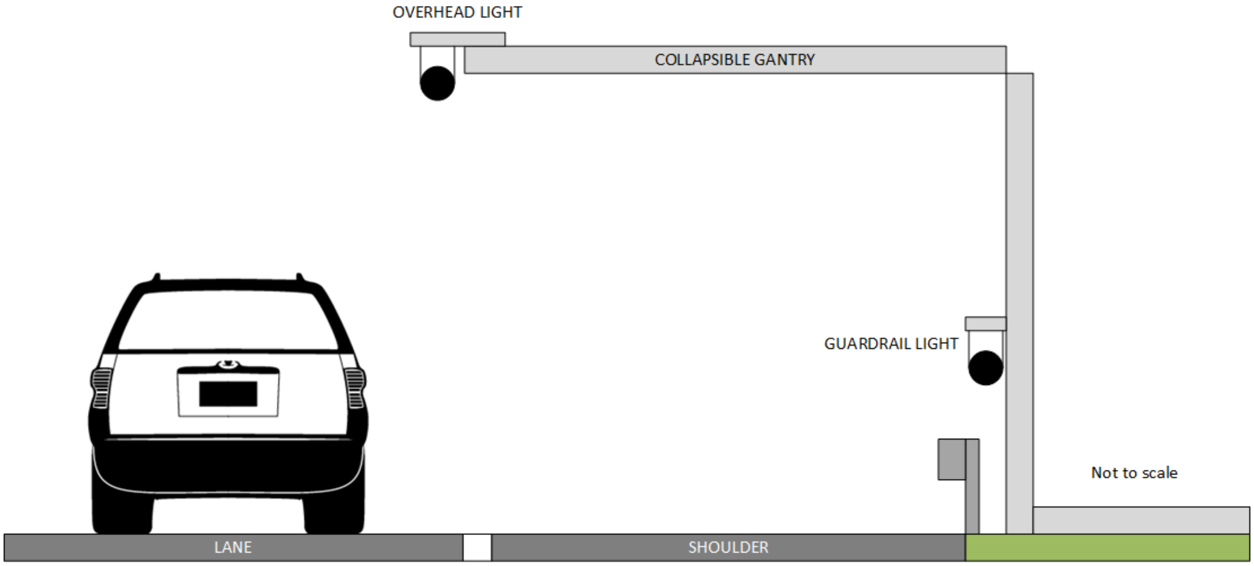

Figure 7. Diagram. Luminaire locations for the overhead sign.

The luminance of the overhead sign was measured under each lighting condition using a Minolta LS-110 luminance meter. Measurements included high and low intensity levels for both the overhead position and guardrail position. Several measurements were taken from the center of the driving lane every 100 ft from the sign, up to 800 ft. The vehicle headlamps were not included in these measurements. Beyond this distance, measurements became too unreliable. Figure 8 shows the mean luminance reading at each distance for each lighting condition. The advantages of the retroreflected light are evident for the overhead light position, as it had a higher luminance level than the guardrail light at all distances for both intensity levels.

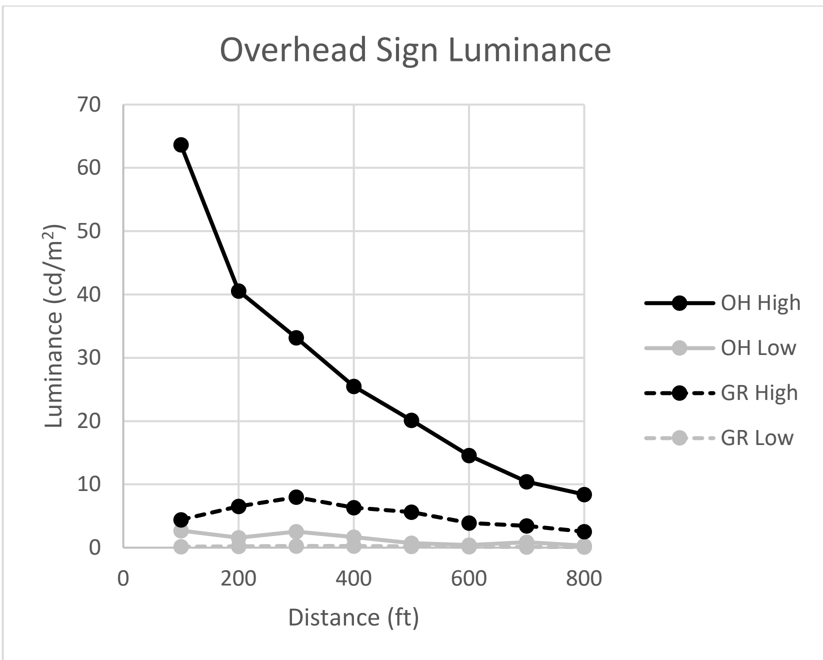

Figure 8. Graph. Overhead sign luminance for each light condition.

Curve Sign Lighting Conditions

For the curve sign, the luminaires were placed at two locations (Figure 9), as follows:

- **Far –** The luminaire was mounted behind the guardrail on the inside of the curve, approximately 1 m high and 115 m away from the sign. This location was selected in order to examine a situation in which the retroreflected light from the luminaire would reach the participant at a location further upstream, where the vehicle's headlamps would be aimed away from the sign due to the geometry of the curve.

- **Near –** The luminaire was mounted behind the guardrail on the outside of the curve, approximately 1 m high and 20 m away from the sign. This location was selected in order to examine a situation in which the visibility of the sign relied less on retroreflectivity and more on a greater illuminance level.

Figure 9. Illustration. Curve sign luminaire locations.

Sign luminance measurements were taken for each light condition (Figure 10). Measurements were taken at several locations along the curve with different viewing angles. A viewing angle of 0° would be directly in front of the sign. The effect of the retroreflected light for the far position is evident, with spikes for both the low and high intensity levels at 22° from the face of the sign (where the measurement was taken directly behind the luminaire). However, the luminance quickly drops off approximately 3° in either direction. The Near High condition provided the most consistently high luminance.

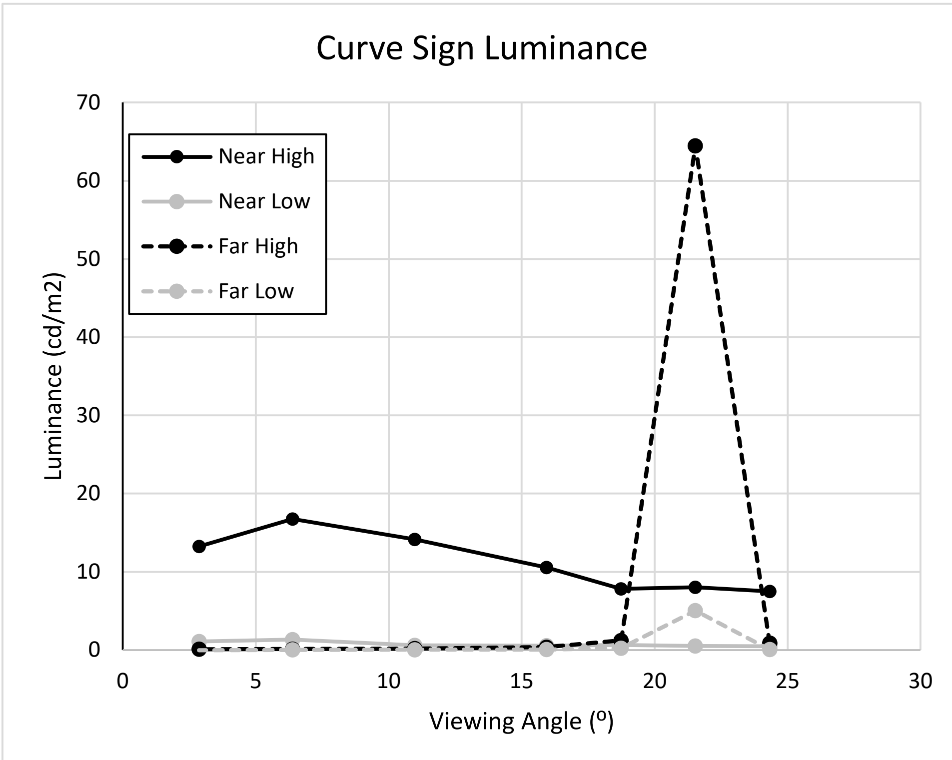

Figure 10. Graph. Curve sign luminance for each light location.

EXPERIMENTAL PROCEDURE

Participant Recruitment, Consent, and Compensation

Recruitment was performed via the VTTI participant database and word-of-mouth. A general description of the study was provided to participants over the phone to determine if they were willing to participate. If they were interested, participants were then screened using a verbal questionnaire to establish whether they were licensed drivers and whether they had any health concerns which should exclude them from the study. Demographic information was collected, and participants were asked about their nighttime driving experience. Eligible participants were scheduled to come to VTTI to participate and were emailed a copy of the informed consent form. Upon arriving at VTTI, participants were taken to a conference room, where they were given a physical copy of the informed consent form and were asked to read and sign the form. An experimenter offered to answer any questions about the consent form. Participants were paid $30 per hour of participation. All experimental procedures were reviewed and approved by the Virginia Tech Institutional Review Board.

Participants

A total of 22 participants completed the study. Originally, 24 were recruited, but two did not show up at the time of testing. A total of 6 younger males, 6 younger females, 5 older males, and 5 older females participated. Drivers met the following criteria:

1. Must have a valid driver's license.
2. Must be a U.S. citizen or hold a green card and be willing to complete a W9 tax form which includes providing their SSN.
3. Must be 18 to 35 years old, or 60 and older.
4. Must not have more than two moving violations in the past 3 years.
5. Must have normal (or corrected to normal) hearing and vision.
6. Must be able to drive an automatic transmission vehicle without assistive devices.
7. Pregnant women were encouraged to speak to their physician about participation before being schedule to participate.
8. Must not have caused an injurious accident in the past 3 years.
9. Must drive at least two times per week.
10. Cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, uncontrolled current respiratory disorders or require oxygen, motion sickness, inner ear problems, dizziness, vertigo, balance problems, uncontrolled diabetes for which insulin is required, chronic migraine or tension headaches.
11. Must not have a history of eye injury or eye surgery.
12. Cannot currently be taking any substances that may interfere with driving ability, cause drowsiness, or impair motor abilities.

Experimental Protocol

Participants were scheduled in pairs based on availability. When participants arrived at VTTI, they were escorted to a conference room, where they read and signed the informed consent form, performed some simple vision tests, and completed paperwork. Participants were then read a script describing the tasks they would perform before being escorted to the experimental vehicles parked outside.

An in-vehicle experimenter accompanied each participant. The experimenters rode in the back seat of the vehicle and ran the data collection equipment while the participants drove. Experimenters instructed participants to drive onto the Smart Road and stop at the far turnaround point. Experimenters then instructed participants to drive a practice lap during which they were given no tasks to perform; instead, the in-vehicle experimenter explained the tasks as participants drove. The in-vehicle experimenters ensured that the participant vehicles remained spaced out so that the headlights of one vehicle would not affect the visibility of the other, and so that the participants never passed each other.

As participants drove up the Smart Road, they first encountered the overhead sign. The words "Port Road" were displayed on the sign. The words on this sign did not change due to the inaccessibility of the sign, so participants were asked only to read the words aloud when they were clearly legible (Figure 11).

Figure 11. Photo. Overhead sign.

Participants then continued uphill until they reached the upper turnaround location. Participants were instructed to read the two words displayed on the curve sign as soon as they were clearly legible. The words displayed on the curve sign changed for each lap. Table 2 lists the possible word combinations. These words were chosen for consistency with previous research.

Table 2. Possible curve sign legends.

Curve Sign Legends	
Gray Park	Oven Cape
Bear Bend	Bear Road
Oven Park	Lake Camp
Long Road	East Camp
Gray Cape	East Bend
Long Port	
Lake Port	

Due to the roadway geometry in the curve sign task, it was possible for participants to observe the sign through the driver's side window by turning their heads. Some participants felt comfortable viewing the sign through the driver's side window, while others felt more comfortable waiting until the sign was closer to their forward view. Participants were instructed to observe the sign when it was comfortable and safe for them to do so, as if they were in a real driving scenario.

Each time participants approached the signs, a different lighting condition was used (including headlamp-only conditions) based on the assigned order. Each order consisted of two observations for each lighting condition and was counterbalanced to minimize order effects.

When all laps were complete, the in-vehicle experimenters instructed participants to exit the Smart Road and return to VTTI headquarters. Once there, participants were given their copy of the informed consent and their payment card, and were then released.

DATA ANALYSIS

Data Reduction

Prior to analysis, a data reductionist viewed the video recorded by the DAS and verified each time a participant correctly read the two words displayed on each sign. This timestamp was used to extract the vehicle's GPS coordinates at each moment they were able to read the signs.

Legibility Distance

For the overhead sign, the legibility distance for each lighting condition was found by calculating the straight line distance between the vehicle's GPS coordinates and the known GPS coordinates for the sign. The following equation was used to calculate the distance in meters:

> ACOS(COS(RADIANS(90-Lat1)) *COS(RADIANS(90-Lat2)) +SIN(RADIANS(90-Lat1)) *SIN(RADIANS(90-Lat2)) *COS(RADIANS(Long1-Long2))) *6371000

Legibility Angle

For the curve sign, the angle at which participants were able to read the sign was calculated by using the coordinates of the participant vehicle, the sign, and a reference point that was directly in front of the sign. The distances between the sign, the reference point, and the participant were calculated using the same equation as above. Then the angle of the participant vehicle relative to the sign face was calculated using those three distances.

Analyses of variance (ANOVAs) were conducted for each of the dependent variables. Significance was determined with an alpha of 95% ($p < 0.05$). For significant factors, Student-Newman-Keuls post hoc tests were conducted to determine which factor levels were significantly different.

CHAPTER 3. RESULTS

OVERHEAD SIGN RESULTS

Table 3 shows the ANOVA results for the legibility distance of the overhead sign. No factors were statistically significant ($p < 0.05$), although the Location*Luminance interaction was very close ($p = 0.0582$).

Table 3. ANOVA results for overhead sign legibility distance.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig
Age	1	68989.2946	68989.2946	2.71	0.1152	
Location	1	2335.7641	2335.7641	1.11	0.3052	
Age*Location	1	1612.2351	1612.2351	0.76	0.3924	
Luminance	1	2172.0174	2172.0174	3.13	0.0923	
Age*Luminance	1	723.1042	723.1042	1.04	0.3199	
Location*Luminance	1	1772.9013	1772.9013	4.04	0.0582	
Age*Location*Luminance	1	12.8567	12.8567	0.03	0.8659	
Total	**7**	**77618.1735**				

The mean legibility distances by the light location and luminance are shown in Figure 12. Although there was no statistical difference among the different conditions, the Guardrail High condition had a mean legibility distance that was approximately 14 m longer than the other conditions. There was virtually no difference among the remaining lighting conditions and the headlamps-only condition.

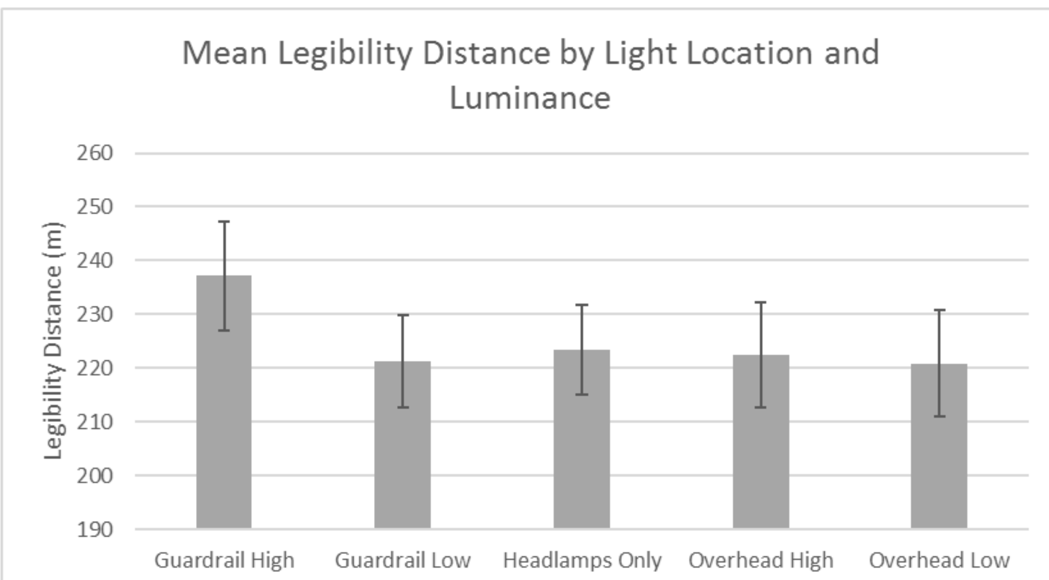

Figure 12. Chart. Mean legibility distance by light location and luminance.

CURVE SIGN RESULTS

Table 4 shows the ANOVA results for the legibility angle of the curve sign. The main effects of Location and Luminance were significant ($p < 0.05$).

Table 4. ANOVA results for curve sign legibility angle.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Sig
Age	1	550.3561	550.3561	2.75	0.1127	
Location	1	132.3640	132.3640	13.25	0.0016	*
Age*Location	1	0.0093	0.0093	0	0.976	
Luminance	1	168.3136	168.3136	19.58	0.0003	*
Age*Luminance	1	2.8146	2.8146	0.33	0.5736	
Location*Luminance	1	4.6354	4.6354	0.66	0.4268	
Age*Location*Luminance	1	11.1977	11.1977	1.59	0.2218	
Total	**7**	**869.6909**				

The mean legibility angle is shown by light location in Figure 13 and by luminance in Figure 14. In both cases, the headlamps-only condition resulted in significantly wider legibility angles—approximately 4° to 6° wider—than the lighted conditions. The far light position resulted in a wider mean viewing angle than the near position, and the low luminance condition resulted in a wider mean viewing angle than the high luminance condition.

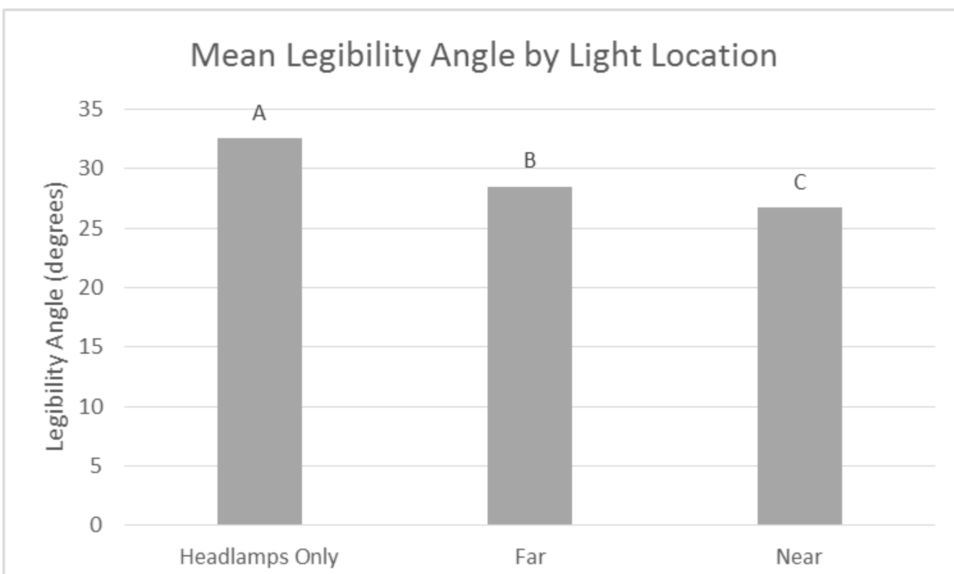

Figure 13. Chart. Mean legibility angle by light location.

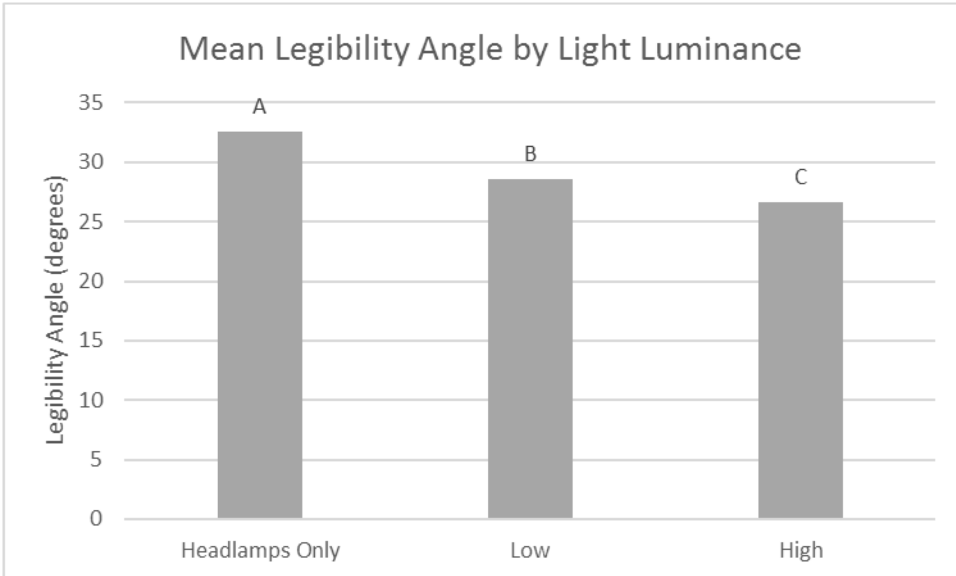

Figure 14. Chart. Mean legibility angle by light luminance.

CHAPTER 4. DISCUSSION

For the curve sign, the headlamp-only condition outperformed all of the lighting configurations, which seems counterintuitive. Figure 15 illustrates the approximate angles for each condition. The mean legibility angles for the near light position and high luminance conditions were roughly equivalent, as were those for the far position and low luminance conditions. Also shown in the figure is the angle at which the luminance was the brightest for the far light position (blue line). Participants tended to read the sign before reaching this peak regardless of the lighting condition. The results indicate that most participants read the sign through the driver side window rather than through the windshield.

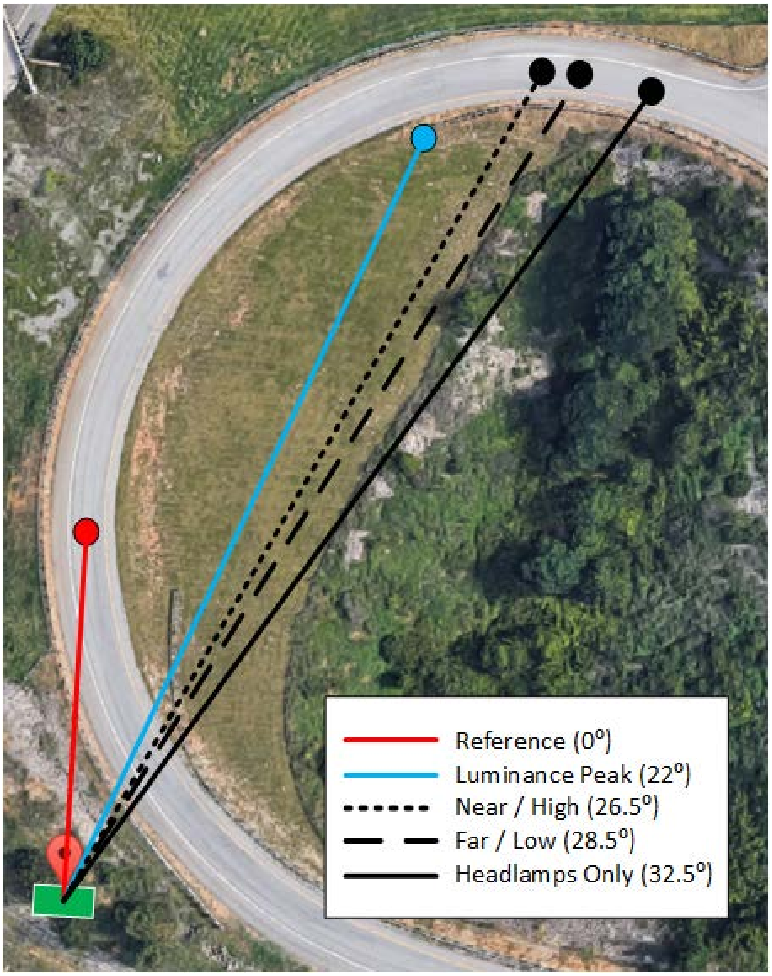

Figure 15. Illustration. Mean legibility angles.

For the headlamp-only condition, the sign was legible almost as soon as drivers cleared the tree line and had line of sight to the sign. Although the vehicle's headlamps would be aimed away from the sign in this scenario, the roadway lighting on the highway adjacent to this end of the Smart Road provided some ambient illumination of the area. Figure 16 shows the view of the curve from the sign's perspective. The blue dot indicates the Far light position. The nearby roadway lighting seemed to provide enough illumination for participants to read the sign from a wide angle, while the different sign lighting conditions reduced that angle. The lighting on the side of the building at the top right of the photo may have also helped, as the angle of these lights may have provided more retroreflected light to drivers coming around the curve. It is also possible that the sign lighting increased the luminance of the sign but decreased the contrast between the legend and the background, resulting in slightly shorter legibility angles.

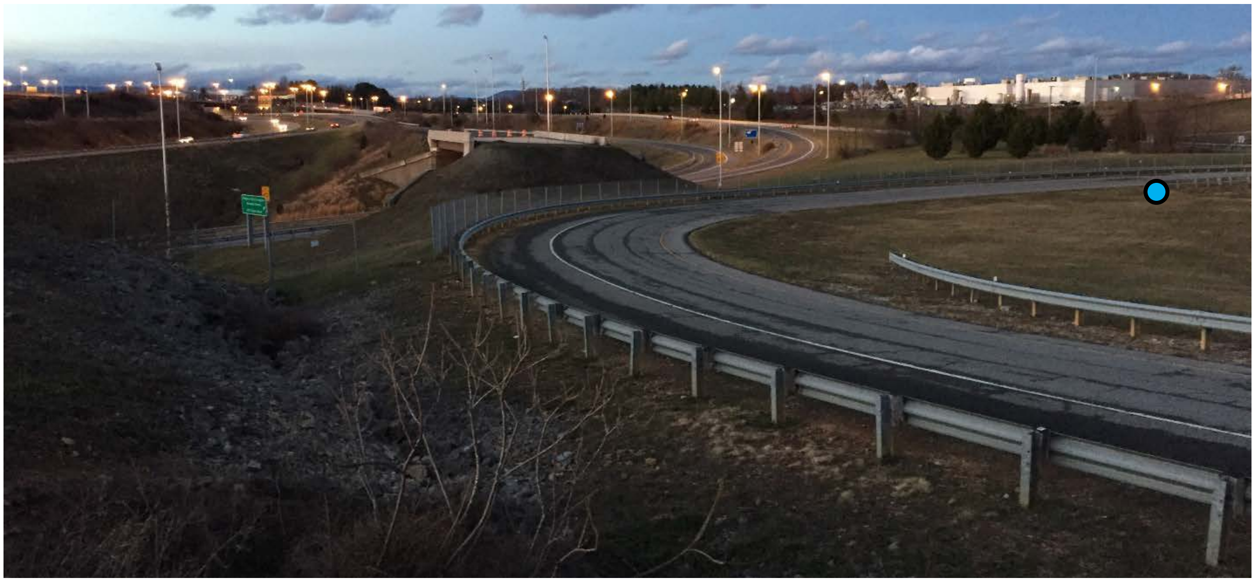

Figure 16. Photo. Roadway lighting adjacent to curve sign.

For the overhead sign, the Location*Luminance interaction was not quite significant, but it was on the borderline ($p = 0.0582$). Looking at the data, it is clear that the Guardrail High condition outperformed all other lighting conditions, but due to the variability in the data, the difference fell just shy of statistical significance. It is possible that a significant difference might be found with a larger participant sample size.

Figure 17 shows the mean legibility distances found in this study along with the mean legibility distances for traditional style lighting found by Carlson et al. (2016). In their study, the high-pressure sodium (HPS) lighting used a single 150-W luminaire mounted at the bottom of the sign and had a mean legibility distance of 218 m (715 ft). The LED lighting used two 66-W luminaires mounted at the bottom of the sign and had a mean legibility distance of 222 m (729 ft). The study by Carlson et al. used the same sign in the same location as this study, in addition to two other types of retroreflective sheeting (the effect of which was not found to be significant).

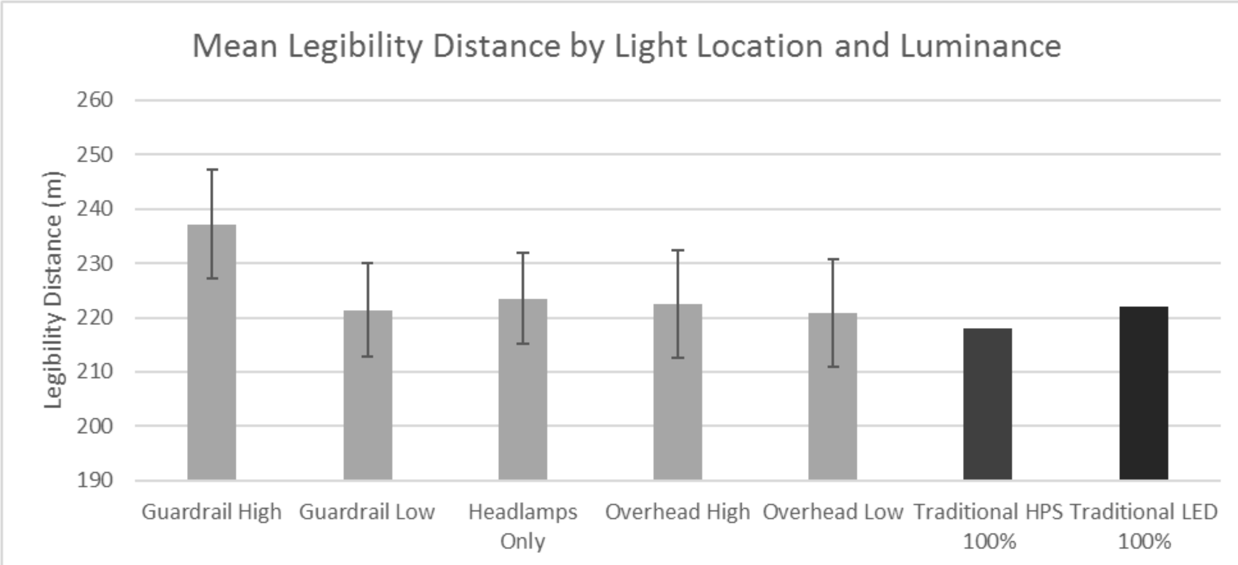

Figure 17. Chart. Mean legibility distance by light location and luminance.

Figure 17 shows that the upstream lighting of the overhead guide sign used in this study resulted in legibility distances that are as good as those produced by traditional style lighting, while using fewer luminaires, and/or less power. The upstream lighting used in this study utilized a single 100-W LED luminaire, compared to two 66-W (132 W total) luminaires in the traditional style LED, and the single 150-W luminaire (188 W total input power) in the traditional style HPS. Additionally, the Low luminance setting, which was achieved by dimming the upstream luminaire by approximately 87%, still provided legibility distances equivalent to the other forms of lighting. Table 5 compares the annual energy costs for lighting a single sign using these methods assuming 10 hours of operation every day at a cost of $0.10 per kilowatt hour (kWh).

Table 5. Estimated annual energy cost for a single-sign lighting system.

Luminaire Type	Watts per Luminaire	Number of Luminaires	Dim Level (%)	Total Wattage	Hours per Day	kWh per Year	Cost per Sign per Year ($0.10/kWh)
Upstream LED (High)	100	1	0	100	10	365	$36.50
Upstream LED (Low)	100	1	87	13	10	47.45	$4.75
Traditional LED	66	2	0	132	10	481.8	$48.18
Traditional HPS	188	1	-	188	10	686.2	$68.62

In this study, and in Carlson et al. (2016), the legibility distances were similar for all tested luminance levels. This suggests that the luminaires could be dimmed to further save on energy costs without diminishing the sign's legibility. Figure 18 shows the estimated annual energy cost adjusted for different dim levels of each of the LED luminaires. While the HPS luminaire used in Carlson et al. was dimmable, dimmable HPS ballasts are more expensive than single power ballasts and are typically not used for sign lighting. Additionally, HPS luminaires do not have a linear relationship between dim level and energy consumption like LEDs. For these reasons, the HPS luminaire is only shown at the 0% dim level. The figure shows that the single upstream luminaire is consistently cheaper to power than the two traditional LED luminaires, although the difference does get smaller as the dim level increases.

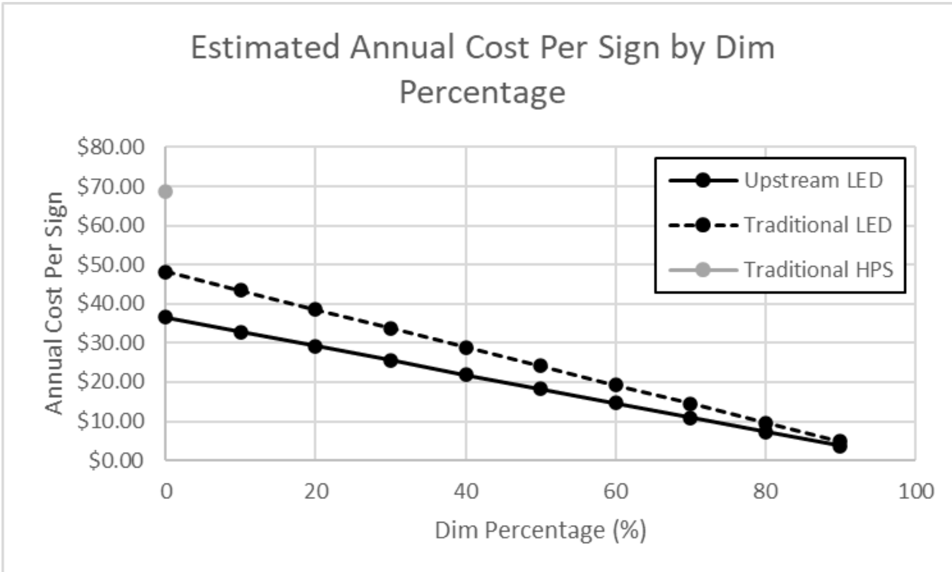

Figure 18. Chart. Estimated annual cost per sign by dim percentage.

In addition to the potential for reduced energy costs for the upstream luminaire, there is also the potential for reduced maintenance costs. The guardrail position for the upstream luminaire was just outside of the guardrail, mounted at a height of approximately 6 ft. A luminaire in this position could potentially be maintained by one operator in a standard vehicle. Maintenance for current sign lighting systems requires a rolling lane closure, which consists of two or three crash cushion trucks, and costs approximately $1,800 for one night (~10 hours). Additionally, a bucket truck with an operator is required to reach the lighting, at a cost of approximately $125 per hour. This comes to a combined cost of approximately $3,050 for one 10-hour maintenance session (F. Woollums, personal communication, August 2, 2017). Since upstream luminaires can potentially be mounted close to the ground on the shoulder of the roadway, they could be maintained without the need for a lane closure or a bucket truck. One potential drawback with placing the luminaire on the shoulder would be an increased risk of damage if a vehicle collided with the post. It may be necessary to restrict this style of lighting to areas which have existing guardrails, or some other infrastructure that the luminaire could be attached to.

Additionally, reducing the number of luminaires needed to light a sign would likely lead to reduced costs. With the current lighting system, common items that need replacing or repairing are the bulbs, which cost approximately $160, and ballasts, which cost approximately $280. While there are currently no lighting systems similar to the upstream luminaire in use today, and it is difficult to predict what maintenance costs may be involved, simply reducing the number of luminaires reduces the potential number of parts that would need to be replaced or repaired.

CHAPTER 5. CONCLUSIONS

For upstream lighting of guide signs in a horizontal curve:

- Upstream lighting provided no benefit for sign legibility in a curve due to the ambient lighting in the vicinity. A benefit might be found in a scenario with no nearby lighting, but this may be rare.
- Placing the luminaire closer to the sign (approximately 20 m) resulted in more consistent luminance from a wider range of viewing angles.
- Placing the luminaire far from the sign (approximately 115 m) resulted in a very high luminance in a small area behind the luminaire but did not increase luminance at other viewing angles.

For upstream lighting of overhead guide signs:

- There was no statistical difference between the upstream lighting, traditional style lighting, and headlamp-only conditions, though there was an increase in the mean legibility distance of the sign (~14 m) when the upstream luminaire was located on the shoulder of the road at the highest luminance setting.
- The upstream luminaire used in this study uses less energy than some traditional style lighting and provides similar legibility distances, especially when dimmed.
- By reducing the number of luminaires needed to light a sign, and placing the upstream luminaire at a low height behind the guardrail on the shoulder, there could potentially be substantial cost reductions in maintenance and upkeep compared to traditional style lighting.
- The luminaire used for the upstream lighting in this study was not designed for this particular application. Due to the potential cost savings, it may be worth investigating adapting this technology for the purpose of sign lighting.
- This study only examined sign legibility in an environment with low visual complexity (an unlit road in a rural setting). Additional research would be needed to examine the effectiveness of upstream lighting in visually complex areas.

REFERENCES

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